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Price One Shilling.

EXPERIMENTS ON THE FORM
OF
SHIPS AND BOATS.

WITH NUMEROUS ILLUSTRATIONS OF MODELS.

BY W. BLAND, ESQ.,

AUTHOR

Of the Principles of Construction in Arches, Piers, Buttresses, &c.

LONDON: JOHN WEALE, 1852.



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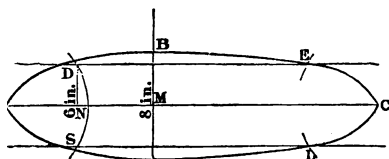
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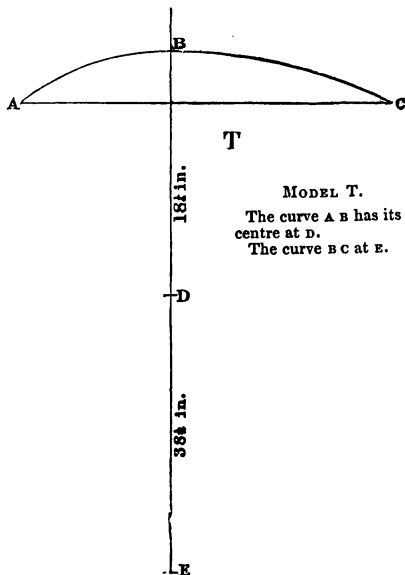
Q

28 1/2 in.

H

80 in.

L K



T

MODEL T.

The curve A B has its
centre at D.

The curve B C at E.

MODEL Q.

The curves A D, A S, have their centres at
D and S.

The curve D B has its centre at H, and the
curve B E at K.

The lines D E and S L are parallel to A C. ∴
parallel to each other: and the distance of D to
N is 3 inches, and the distance of B to M is
4 inches; therefore the proportionate distances
of these two lines D N and B M are to each other
as 3 : 4.

HINTS
ON
THE PRINCIPLES WHICH SHOULD REGULATE
THE
FORM OF SHIPS AND BOATS ;

DERIVED FROM ORIGINAL EXPERIMENTS.

WITH NUMEROUS ILLUSTRATIONS OF MODELS.

BY
W. BLAND, ESQ.

**AUTHOR 'ON THE PRINCIPLES OF CONSTRUCTION IN ARCHES,
PIERS, BUTTRESSES, &c.'**

[REPRINTED FROM THE CIVIL ENGINEER AND ARCHITECT'S JOURNAL]

London :
JOHN WEALE, 59, HIGH HOLBORN.

M.DCCC.LII.

HUGHES, PRINTER,
KING'S HEAD COURT, GOUGH SQUARE.

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Hist. 2 Series
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EXPERIMENTS

ON

THE FORM OF SHIPS AND BOATS.

INTRODUCTION.

MUCH difference of opinion having of late years prevailed respecting the true form of Ships and Boats, I have been induced to make a Series of Experiments with models of wood, for the purpose of ascertaining, by a careful notation of results, what may be considered as the governing laws; and I flatter myself I have been successful, in some measure, in detecting a few of the leading principles which influence the speed, the stability, and the safety of vessels impelled by the wind, the oar, and steam.

CHAPTER I.

This chapter contains the particulars of experiments undertaken to gain a knowledge of the laws of water with regard to the head resistance it makes against bodies floating upon its surface, and impelled forward by some force, as the wind, the oar, and steam.

To this end, four pieces of deal were selected, of the same

uniform density and thickness, and each 12 inches long, but varying in width.

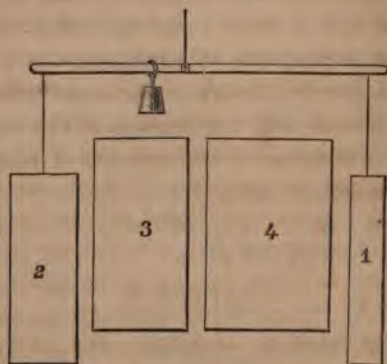
No. 1 model, 2 inches wide and 12 inches long.

No. 2 model, 4 inches wide and 12 inches long.

No. 3 model, 6 inches wide and 12 inches long.

No. 4 model, 8 inches wide and 12 inches long.

These were, two at a time, attached by strings to the two ends of a balance-rod, of the length of $20\frac{1}{2}$ inches; a thin string, acting the part of a fulcrum whilst suspending the rod, was so put on the rod as to admit of being readily slipped along it at the will of the experimenter; the other end being fastened to the small extremity of a long pole, for the purpose of reaching far enough over a pond of water to tow the model upon the surface, clear of all obstacles.



The balance-rod. Scale $\frac{1}{12}$.

The two models selected for experiment were then drawn into the water, and whichever of them preponderated, by meeting with greater resistance than the others, had the suspending string shifted along the balance-rod until both the floating bodies attained an equilibrium of resistance, when the meas-

of their respective resistances was denoted by the inverse length of the arm or lever to which they were fastened. The shorter arm was made, in each experiment, to balance correctly the longer arm, by the means of a moveable weight applied to the shorter arm.

Experiment 1.

Models.	Width.	Length.	Weight.	Difference.	Weight.
No. 1.	2 in.	12 in.	10 oz.	} $1\frac{1}{8}$ inch of lever, or 2 oz.	
No. 2.	4 in.	12 in.	10 oz.		

Experiment 2.

No. 2.	4 in.	12 in.	$12\frac{3}{4}$ oz.	} $1\frac{1}{8}$ inch of lever, or 2 oz.	
No. 3.	6 in.	12 in.	$12\frac{3}{4}$ oz.		

Experiment 3.

No. 3.	6 in.	12 in.	19 oz.	} $1\frac{1}{8}$ inch of lever, or 2 oz.	
No. 4.	8 in.	12 in.	19 oz.		

In these experiments the dimensions of the models were to each other as 1, 2, 3, and 4; and the head resistance, compared two at a time, and of equal weight, gave the same results; consequently, the law of the head resistance is, that it increases directly with the increase of the square surface opposed; and therefore in this instance of equal additions, assumes the arithmetic ratio.

CHAPTER II.

EXPERIMENTS MADE TO ASCERTAIN THE LAW OF THE RESISTANCE OF WATER AGAINST THE INCREASE OF WEIGHT.

Experiment 4.

For this purpose, two model boats were selected of equal draught, and into one was put a 1lb. weight; and being drawn on the water by the same balancing-rod which was employed in the preceding chapter, and the difference of the resistance determined as before, the law revealed itself thus:

With 1 lb. weight, the short arm was $7\frac{1}{2}$ inches long.

With 2 lb. „ „ $6\frac{1}{2}$ inches long.

With 3 lb. „ „ $5\frac{1}{2}$ inches long.

That is to say, the resistance increases directly with the weight.

CHAPTER III.

OF LATERAL RESISTANCE.

A ship impelled through the water by wind acting on its sails depends for speed in no small degree upon the lateral resistance it makes, and the situation of the centre of that resistance.

The following experiments were undertaken to ascertain the law, and how influenced.

Experiment 5.

First, around and near the midship section of a model ship was fastened, yet readily moveable, one end of a line; the other end left to be taken in hand, a sufficient quantity of line being allowed between to tow the vessel through the water towards the shore, when placed at some distance from the same.

And second, the model put on the water was repeatedly drawn to the shore, and the point of fastening of the line as frequently shifted. The effects were these :

When the point of fastening was situated a trifle towards the head, the line on being pulled drew the head forward ; and when fixed rather astern, then the stern was drawn forward ; thus proving there existed a point or centre of balance. By carefully moving the place of fastening, it was readily found upon measurement, to be situated exactly in the mid-length of the keel and part of the projecting cutwater, the vessel floating upon a level keel.

During the carrying out of the above investigations, it was observed, that when the vessel was made by the line to progress forwards, as well as sideways, the centre of lateral resistance moved also forwards; and this, of course, was in consequence of its bows meeting with greater resistance than when moved exactly sideways.

The reason is obvious; first, because the water at the bows became condensed, and thus made greater resistance; and secondly, the water being driven up against the bows, higher than the surrounding fluid, produced its effect.

The above-named resistance equalled, it was found, about one-twelfth of the length of the body immersed; but which proportion must vary, however, with the speed.

The centre of gravity in all these experiments seemed to have little or no influence with regard to the centre of lateral resistance, it being regulated by the perpendicular surface exposed to the water; and the centre of which was the centre of lateral resistance, when the force of the water acted at right angles to that surface.

CHAPTER IV.

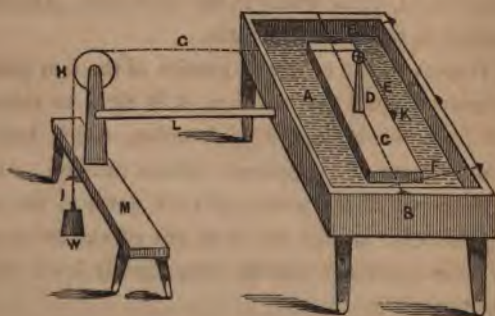
OF STABILITY AND ITS LAWS,

Experiments relative to the Law of Stability when the Width or Beam is increased.

For this purpose four pieces of deal were chosen of the following dimensions:

No.	Length.	Width.	Depth.	Weight.
1.	15 in.	3 in.	2 in.	1 lb. 8 oz.
2.	15 in.	4½ in.	2 in.	2 lbs. 3 oz.
3.	15 in.	6 in.	2 in.	2 lbs. 13 oz.
4	15 in.	7½ in.	2 in.	3 lbs. 7 oz.

In order to ascertain the stability of each respectively, as they in turn floated upon the water, a small moveable mast, 3 inches high, having a hole through the top, was fixed on the upper surface, and in the centre of gravity; one end of a line was looped over a nail driven into the side of the wood, when the other end was first passed through the hole, then continued on over a pulley, and at the end a small bag was attached for the convenience of holding weights. Into the two extremities of the same piece of wood as No. 1, nails were driven lightly, and at the points where the centres of the wood cut the line of flotation. Over the heads of these nails a string of sufficient length was secured by two loops, the other ends of the strings being then made fast to nails driven into the side of the cistern of water, and at the water level, but in the direction opposite to the string going over the pulley, with the view of counteracting the force of the weights.



A, B, the tank, and A, the surface of the water.—c, the model.—D, the mast through which the line E, G, H, I, passes, being first attached to the model by a nail at K.—W, the weight.—M, the stool which carries the pulley.—L, a shore to steady and support the pulley.

All being prepared, the weights were put into the bag until the side of the piece of wood opposite the pulley heeled down into the water to the depth of 1 inch, previously marked out; and by this means, the scale, as will be presently given, was obtained.

Experiment 6.—The Scale and Table A.

No.	Length.	Width.	Depth or thickness.	Floating depth.	Stability.	Ratio.
1.	15 in.	3 in.	2 in.	1 in.	2 oz.	1 = 3.2
2.	15 in.	4½ in.	2 in.	1 in.	2.3 7 oz.	3½
3.	15 in.	6 in.	2 in.	1 in.	3.5 14 oz.	7
4.	15 in.	7½ in.	2 in.	1 in.	4.4 22 oz.	11

The conclusions to be drawn from this scale are, that with the same length the ratio of stability is at its limit of rapid increase when the width is just one-third of the length; or, as 5 : 15 (see No. 2), being nearly in the cubic ratio. Afterwards, it approaches to the arithmetic ratio.

With respect to the centre of gravity of the four pieces of wood employed upon the occasion, it is right to state they were cut from the same plank of timber, which had been selected on account of its apparent uniform density. And the models, when put on the water, all sunk down to the middle of their thickness, or just one inch out of the two; consequently, their centres of gravity were exactly level with the surface of the water.

Experiments to ascertain the Law of Stability as regards the Increase of Length, the Width and Thickness of the Floating Bodies being constant.

For this purpose, six pieces of wood (deal) were employed, and of the following dimensions and weights :

Experiment 7.—The Scale and Table B.

No.	Width.	Length.	Weight.	Stability.	Ratio.
1.	3 in.	3 in.	1 $\frac{3}{8}$ oz.	$\frac{1}{4}$ oz.	1
2.	3 in.	6 in.	2 $\frac{3}{8}$ oz.	$\frac{3}{4}$ oz.	3
3.	3 in.	9 in.	4 nearly	1 $\frac{1}{8}$ oz.	4
4.	3 in.	12 in.	5 $\frac{3}{8}$ oz.	1 $\frac{3}{8}$ oz.	5
5.	3 in.	15 in.	7 oz.	1 $\frac{5}{8}$ oz.	6
6.	3 in.	18 in.	8 $\frac{3}{4}$ oz.	1 $\frac{3}{4}$ oz.	7

Here the scale of increase is as 1 : 3 when the length is doubled ; but after this it takes the arithmetic ratio.

Further Experiments to determine how the Law of Stability operates when the Length and Width of Floating Bodies are constant, the Thickness alone being varied.

The following were the dimensions of the models of deal selected :

Experiment 8.—The Scale and Table C.

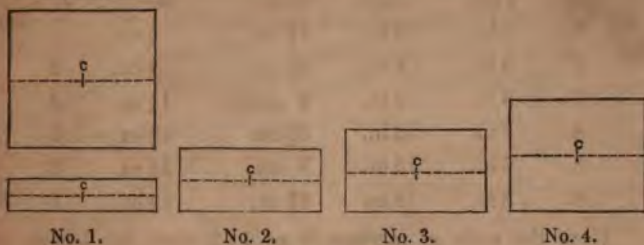
No.	Width.	Length.	Thickness.	Weight.	Stability.	Ratio.
1.	3 in.	9 in.	$\frac{5}{8}$ in.	4 oz.	1 $\frac{1}{4}$ oz.	2 $\frac{1}{2}$
2.	3 in.	9 in.	1 $\frac{1}{4}$ in.	8 oz.	1 $\frac{3}{4}$ oz.	3 $\frac{1}{2}$
3.	3 in.	9 in.	1 $\frac{3}{4}$ in.	12 oz.	1 $\frac{1}{2}$ oz.	3
4.	3 in.	9 in.	2 $\frac{1}{4}$ in.	16 oz.	1 oz.	2
5.	3 in.	9 in.	3 in.	20 oz.	$\frac{1}{4}$ oz.	$\frac{1}{2}$ *

* Or next to nothing, being a cube.

In this Table it is seen that when the thickness is in the proportion of 5 : 12 of the width (as in No. 2), ~~or~~ the depth of flotation one-fifth, say, of the beam, and the centre of gravity at the water level, the stability is at its greatest.

And further, that 4 oz. in weight placed low (as in No. 1 of this Table), more than counterbalances 16 oz., as in (No. 4), when situated high.

Mid-sections—c, the centre of gravity and line of flotation.
No. 5.



Scale $\frac{1}{4}$ inch to 1 inch.

If these three Tables be admitted as correct, it establishes the rule, that the line of flotation, with regard to depth, and as it affects stability, should be one-fifth of the breadth of the beam, when the body partakes of the parallelopiped form; the centre of gravity being preserved at or just within the level of the surface of the water of the floating body.

Let it be here repeated, relative to all the above experiments, that each piece of deal sunk in the water to half its depth or thickness; therefore, their respective centres of gravity were always on a level with the surface of the water.

CHAPTER V.

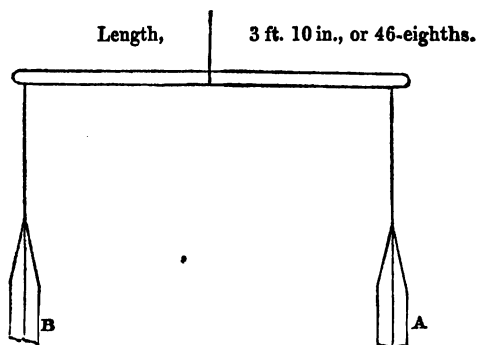
The whole body of a ship comes next into consideration; and with the view of investigating the same in a perfect and lucid manner, it will be advisable to divide the subject into three parts—as ‘the Bows,’ ‘the Stern,’ and ‘the Middle.’

OF THE FORM OF THE BOWS.

The experiments which were put into practice for ascertaining the law relative to the difference of form when exposed

to the action of water are arranged severally as follows ; the diagram beneath exhibits the mode by which the test of the speed was applied.

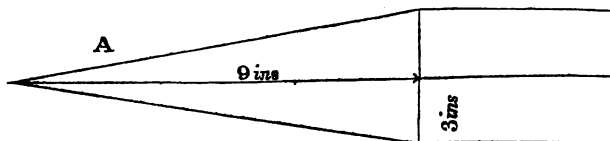
The balance-rod. Scale $\frac{1}{16}$ th of an inch to an inch.



Experiment 9.

First. The form of the model selected was that of an isosceles triangle, having the perpendicular distance of the base from the apex three times the width of the base.

Weight 12 oz. ; thickness $1\frac{1}{4}$ inch.

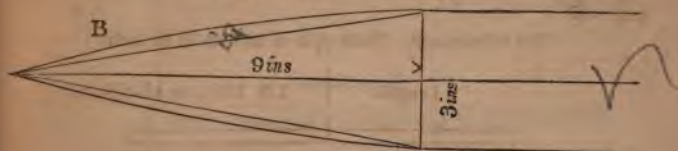


Experiment 10.

Second. This form was an isosceles spherical triangle, of same perpendicular length and width at the base as the preceding, but having the two sides uniting the base with apex convex ; the curve subtending at the middle of the length

one quarter of an inch beyond the straight lines uniting these two points.

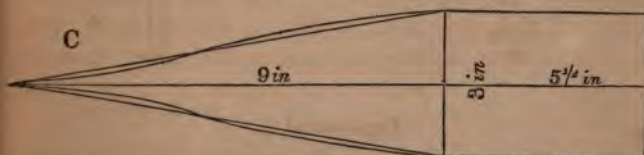
Weight and thickness as A.



Experiment 11.

Third. The form of an isosceles triangle, with its two sides waved; and the dimensions in other respects the same as models A and B.

Weight and thickness as B.



These three models of deal, A, B, C, of the same precise weight, depth, width, and length, were tested on the water against each other, by the balance-rod, and the following results were obtained:

Model B had the greatest speed,

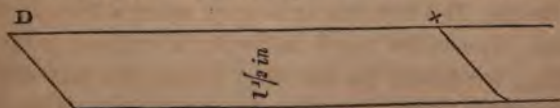
Model A the next,

Model C the least.

But the difference between them was trifling.

Experiment 12.

The model A was then tried against the fourth model D, of



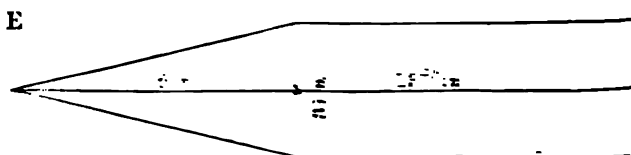
the same form of bows, dimensions, and weight, but having its lower isosceles sides bevelled off.

The difference of speed between these two was not perceptible.

Experiment 13.

The next test of bows was with those of less sharpness, and compared first with the sharp-modelled bow A, and then with others of less acute angles.

Weight 141 lb. thickness $1\frac{1}{2}$ inch.



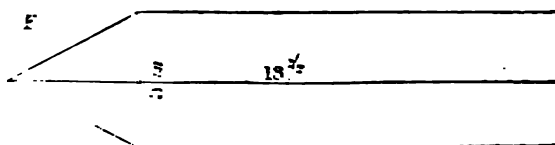
The isosceles triangle form of bows E had its perpendicular distance from the base 6 inches, yet having the width, depth and weight precisely the same as A.

The conclusion arrived at was, that the speed of A : E :: $6\frac{1}{2}$: 6.

Experiment 14.

The speed of E was then tested with the speed of the model F, having its base and sides equilateral.

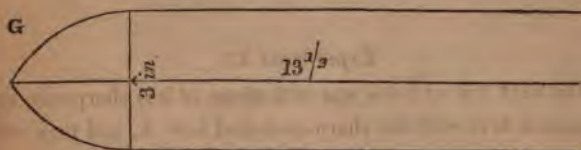
Weight and thickness as E.



The result gave the speed in favour of E : F :: 3 : 2.

Experiment 15.

The model F was tried against G, a model having its bows a spherical equilateral triangle.

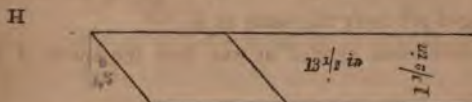


The weight of model G the same as F; the speed in favour of F was, $F : G :: 6 : 5\frac{1}{2}$.

Experiment 16.

The last test was between the equilateral triangle bows F, and the bows H, of the same dimensions and similitude; but having its isosceles sides bevelled off, the angle at the cut-water being 45° .

Weight and thickness as F.



The speed of H was to that of F : : 5 : 4.

The bevelled bows of H threw the water off admirably, or rather it may be said to ride over it; it was always dry during the experiment; whereas F shipped water continually over the bows with the least extra speed.

The conclusions obtained by the experiments in this chapter are, that the more sharp the forms of the bows the less is the resistance from water; and when a gentle curve is given to the bows, the speed is rather improved. Again, by the beveling of short bows, the speed becomes greatly improved; but this is not so apparent in the long and sharp bows. The

bevelled short bows rode over the water, as it were, or at was in a degree lifted by it, and therefore did not throw water up like the perpendicular side bows.

CHAPTER VI.

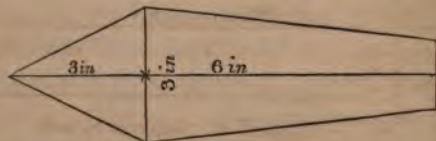
EXPERIMENTS RELATING TO THE STERN.

Experiment 17.

First, with the sides parallel and tapered. Two models having the same form of bow, an isosceles triangle of 3 inches perpendicular distance from the base, and 3 inches wide; the bodies attached 6 inches long; one of them with parallel sides, the other tapered as shown in the diagram; scale $\frac{1}{4}$ to 1 inch.



No. 1.—Weight 10 oz.; thickness $1\frac{1}{2}$ inch.

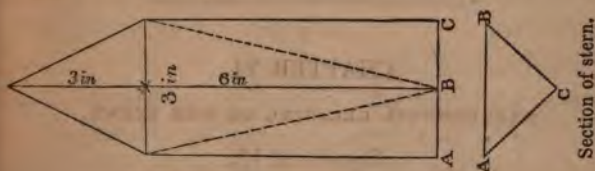


No. 2.—Weight 10 oz.; thickness $1\frac{1}{2}$ inch.

Upon being tested against each other, there appeared a slight degree of speed in favour of the parallel-sided model (No. 1), and decidedly greater stability than was possessed by the tapering-sided model (No. 2).

Experiment 18.

A third model (No. 3) of the same bows, length, width, and weight, was tested against No. 1; but having its sides bevelled towards and at the stern.

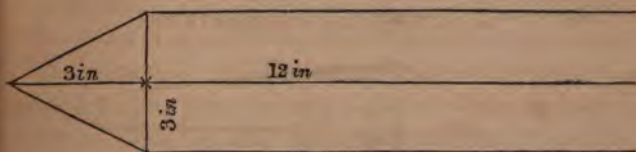


No. 3.—Weight 10 oz.; thickness $1\frac{1}{4}$ inch.

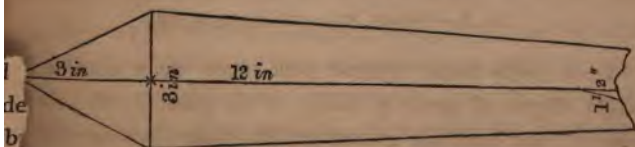
The result of the trial was, that the speeds of No. 1 and No. 3 were equal; but No. 3 was inferior in stability, and sank deeper into the water than No. 1, and was less steady in its course.

Experiment 19.

Two models having the same form of bows as the preceding (Nos. 1 and 2), but with the bodies 12 inches long; one of them with the sides parallel, the other tapered, as exhibited in the diagrams marked Nos. 4 and 5.



No. 4.—Weight 17 oz.; thickness $1\frac{1}{4}$ inch.



No. 5.—Weight 17 oz.; thickness $1\frac{1}{4}$ inch.

When the models (Nos. 4 and 5) were tested together the speed of No. 5, having tapered sides, was considerably inferior to the one with parallel sides; the proportion in speed of the parallel-sided model to that of the tapered sides :: 3 : 2; and respects stability, the parallel-sided model had very much the advantage.

Experiment 20.

Again, experiment made between two models of the form of bows, &c., as those just tested, but with the bows each lengthened to 18 inches; one having the sides parallel the other tapered; indeed, both after the forms of Nos. 4 and 5, but longer by 6 inches. The weight of each equalled 7 oz.; thickness $1\frac{1}{2}$ inch.

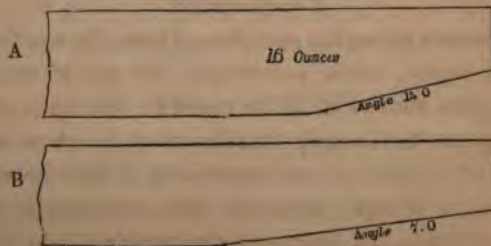
The speed, in this instance, between these models was so dissimilar as in the trial with the two former models (Nos. 4 and 5); but still the tapering proved injurious, and the proportion of 5 : 4.

In the experiments here given, they prove most decidedly that tapering the whole length of the body of a ship is detrimental to speed.

The experiments next undertaken relate to the tapering of the under part or bottoms of ships towards and at the stern.

Experiment 21.

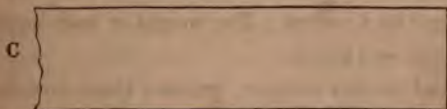
Two models of the same form of bows, and having



the respective lengths, breadths, thickness, and weight, equal; but one of them cut inclined up at an angle of 14° , commencing at one-third of the length from the stern; the other also cut as inclined up, but at an angle of 7° , and commencing at the mid-length, as in the diagrams A and B, which when tested together, A beat B in speed by a trifle.

Experiment 22.

Again, a third model marked C, of the same dimensions and weight as A, but the bottom not cut inclined up; upon being tested with A, A had the greater speed of the two.



Weight 16 oz.

The model C was then tested with a model E, which differed from C by having its sides towards and at the stern inclined by a gentle curvature, commencing from near the midship. The balance-rod gave the speed greatly in favour of the curved sides; for the model E required the additional weight of 2 oz. to be put into it to reduce its speed to an equality with the model C. The weight of each model equalled 16 oz., therefore the speed of E was superior to the speed of C by one-eighth of the weight.

Experiment 23.

Two models having the same form of bows, likewise the same breadth, length, depth, and weight; but one of them with parallel sides and bottom as the model C; the other, with the sides tapered curvilinearly towards and at the stern, and the bottom cut up inclined, and commencing in both instances at one-third, or 6 inches from the stern; the length of each model 18 inches, and their respective weights 17 oz.

The difference of speed between these two models was great and on the side of the curvilinear-formed stern, and nearly in the proportion of 3 : 2.

Experiment 24.

When the parallel-sided model (the one employed in the last experiment) had its sides made also curvilinear, but not the bottom, its speed, upon again testing the two last models together, was found to be improved very materially.

These latter experiments were tried against each other by weights, as well as by the difference of the length of lever, and the results were, that the model with curvilinear sides and inclined-up bottom, beat in its speed the model with parallel sides and bottom, and required the additional weight of 8 oz. to be put into the former to reduce its speed to an equality with the latter.

Experiment 25.

Upon shaping the parallel sides only to the curvilinear form of the swifter model, the speed of it was so far increased, in consequence, that 3 oz. extra weight was then sufficient to equalize the speed of both.

Experiment 26.

The curvilinear sides of the original parallel-sided model were next reduced to straight lines, the convexity of each being removed; and when tested with the swift model, it was found to be considerably injured in its speed, having lost by the alteration of the curves to straight lines, to the amount of $1\frac{1}{2}$ oz. in weight; because the now straight-line tapered stern required the additional weight of $4\frac{1}{2}$ oz. to be put into the swifter model, to equalize their speed, instead of 3 oz. when the sides were curvilinear.

The curve employed in the foregoing experiments was the *segment* of a circle, which subtended at the centre of the

th of the straight line in the proportion of $\frac{1}{4}$ of an inch in ches. The angle of the tapering, measured by straight s, was 10° .

Experiment 27.

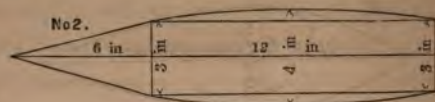
Having altered the curvature of the sides in another model, from the subtension of $\frac{1}{4}$ inch to $\frac{1}{2}$ inch in 6 inches of the th, the speed upon trial was proved to be deteriorated to amount, in weight, of 1 oz. out of 2 oz., the previous d, or injured by one-half. Indeed, after many experiments e with the view of thoroughly testing the principle of ring the sides and bottoms of models towards and at stern, the results gave equal benefit; meaning, that when sides were tapered, the improvement in the speed which wed was, when estimated by weight, equal to 4 oz. And tapering of the bottom towards and at the stern produced rovement in the speed likewise equal to 4 oz.; or 8 oz. urther, in superiority of the model having its sides and om continued parallel and level.

CHAPTER VII.

EXPERIMENTS RELATING TO THE MIDDLE.

he segment of a circle which subtends $\frac{1}{4}$ inch in the centre base line of 6 inches having proved beneficial towards the motion of speed when applied at the bows, as given in Experiment 10, and at the stern in Experiment 24, induced a er trial of the same curve in the experiments annexed.





Scale, $\frac{1}{8}$ inch to 1 inch.

Experiment 28.

The two models (Nos. 1 and 2) of the same bows, length and weight, but differing in their sides, one being parallel other convexed; the rise at mid-length being $\frac{1}{2}$ an inch to whole length of side of 12 inches, according to the proportion before adopted.

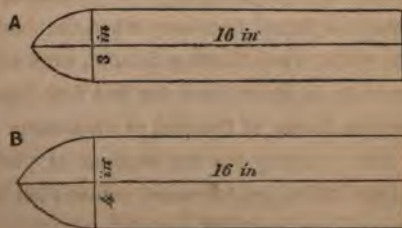
Upon being tried against each other at the ends of a balance-rod, it appeared that the speeds were equal. This makes a third instance of the good qualities of the curve in promotion of speed over the straight line.

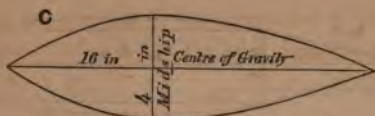
In this experiment is seen greater breadth of beam, and indeed to one-fourth; yet, by the adoption of the curve in question, equal speed is obtained.

Experiment 29.

Segments of circles of different diameters were further applied and tested against two parallel-sided models; one of same breadth of beam, the other of less beam by one-fourth part; all three however of the same weight, 23 ounces.

Scale, $\frac{1}{8}$ inch to 1 inch; thickness, 2 inches.





Modelled from the horizontal section of the sole fish.

The first trial took place between the models A and C. The result gave the speed of C to be greater than A, in the proportion of 5:4; or taken in weight, equal to 8 oz.; because the model C required to be loaded with that weight extra, to retard its speed to an equality with the speed of A.

Experiment 30.

The second trial was between the models A and B. In this instance, the speed of A beat that of B, by the extra weight of 4 oz.

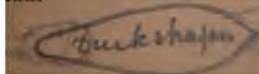
Experiment 31.

In the third trial the speed of the model C beat that of the model B, by 12 oz. extra weight.

Experiment 32.

The model C was drawn through the water having its stern or sharper end foremost; and in consequence of so doing, the speed was reduced. Moreover, by the sharper end going foremost, the steadiness of its course was in a great measure destroyed, the model requiring a piece of keel to be attached at the aft end to cause the body to preserve a straight course; and which was not found necessary when the bluffer end or bows meet the water when floating upon an even keel.

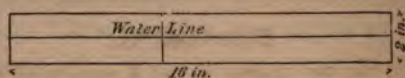
The inference to be drawn from the last four experiments is in every respect in favour of the bird or duck-shaped model C; at the same time pointing out the wisdom of preferring the bluffer or larger end to go foremost, rather than the sharper end.



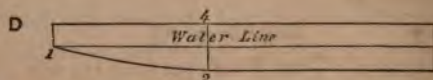
The pointed end acts as keel when bluffer end is foremost as it sinks in

CHAPTER VIII.

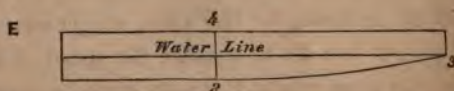
The subjoined experiments were undertaken to ascertain effects of the curving up of vessels from the midship section, both to the head and stern. To this end, three models were made of the precise form and size of C in the preceding chapter, with the exception of their being varied from it delineated below; scale $\frac{1}{8}$ inch to 1 inch.



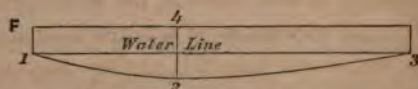
Side view of model C.—Weight 22 oz.



The model with the bows from 1 to 2, cut inclined up.



The model with the stern from 2 to 3, cut inclined up.



The model with both the bows and stern cut inclined up.

The inclination upwards, or curves at both the bows and stern of these diagrams, are sections of two circles having their centres in the same straight line (numbered 2, 4,) at the midship sections of the diagrams, when produced indefinitely in the direction of 2, 4; and their circumferences pass through the points 1 and 2, 2 and 3.

Experiment 33.

The models C and D being first made of equal weight, were tested as to their speed; and it was found that the model D with its bows cut inclined up, beat C with the level bottom by 8 oz. additional weight.

Experiment 34.

Next, the model C was tested with E, having its stern cut inclined up; when C was again beaten in its speed, the model E carrying with equal speed 6 oz. extra weight.

Experiment 35.

After this, the two models D and E were tried against each other, and the advantage of speed was, in weight, 2 oz. on the side of the model D.

Experiment 36.

Lastly, the models C and F were put upon the water together, the latter having both its bows and stern cut inclined up. The difference in their speed was altogether in favour of F; indeed, equal to 12 oz. or more, for this extra weight was not sufficient, when put into F, to equalize the speed of the two models; but the great weight F already carried was quite load enough, without sinking too deep into the water.

The conclusion to be here drawn is, the positive good effects from the cutting or curving up of both the head and stern of vessels, when commenced from the midship section, and extending as far at least, each way, as the load water-line.

F was not tried stem foremost (nor E.)

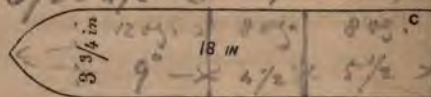
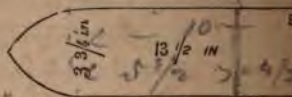
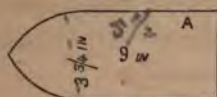
CHAPTER IX.

OF THE MIDDLE LENGTH OF A SHIP.

The following experiments were undertaken to ascertain the properties of the middle length, or centre body of a ship.

Three models having parallel sides, flat bottoms, the same form of bows, and all of the same breadth of beam, namely $3\frac{3}{4}$ inches; yet varying in their lengths as follows, but all of equal weight: length of A, 9 inches; B, $13\frac{1}{2}$ inches; C, 18 inches.

Scale, $\frac{1}{8}$ inch to 1 inch. Weight of each 20 oz.



This difference in their respective lengths was made for the purpose of ascertaining the effects of increased length, with regard to speed, and the power of carrying weight.

Experiment 37.

The model A was tested by the balance-rod with B, which beat in speed A, so as to require the weight of 8 oz. to be put into B, to retard its speed to that of A.

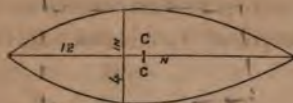
Experiment 38.

B being tested with C, C required the weight of 8 oz. to be put into it, to cause the speed to equal B, being the same difference as in the first experiment; and therefore the speed of C will equal the speed of A, and carry at the same time 16 oz. additional weight.

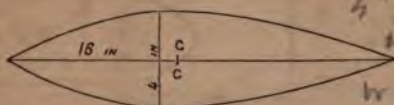
The same law exists in models of a different form, as instanced in the following experiments. Three models were tested against each other to discover the difference in their speed, having level bottoms, of the same weight and breadth.

Below model A had 8 oz. more weight and B had 8 oz. more weight and C had 8 oz. more weight and therefore C was the fastest.

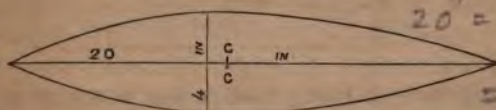
of beam, but varying in their lengths; scale, $\frac{1}{8}$ inch to 1 inch.



No. 1.—Weight $22\frac{1}{2}$ oz.; thickness 2 inches.



No. 2.—Weight $22\frac{1}{2}$ oz.; thickness 2 inches.



No. 3.—Weight $22\frac{1}{2}$ oz.; thickness 2 inches.

Experiment 39.

No. 1 was so far inferior in speed to No. 2, that an extra weight of 12 oz. was put into No. 2 before its speed was retarded to the same rate of speed as No. 1.

Experiment 40.

Now No. 3 beat in speed No. 2, so as to require 12 oz. to be placed in No. 3 to bring their speed to an equality.

The inference to be drawn from the foregoing experiments is, that additional length gives increase of speed; or will carry the weight through the water with proportional less resistance. The stability, likewise, increases with equal ratio, as given in Experiment 7. The cause of this less resistance must arise, in the first instance, from the same dimensions of bows, and breadth of beam clearing the way for the increased length of the after-part; and in the second, in consequence of the

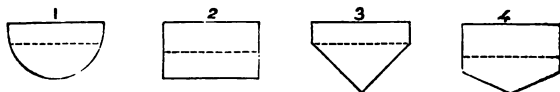
increased length, which is followed by increased surface bearing; therefore the whole weight displaces less depth of water: hence arises less resistance when the length alone is concerned. With respect to the increase of the breadth of beam improving speed, the cause proceeds from the curve and the enlarged surface-bearing combined; otherwise, the result of the experiments (Nos. 1 and 2, &c.) would have decided to the contrary.

CHAPTER X.

FORM OF THE MIDSHIP SECTION.

This chapter relates to the form of the midship section,—its importance as to a ship's speed, and to determine which the experiments, as detailed in the subsequent pages, were resorted to.

Four models, all of the length of 14 inches, and 4 inches wide, having their sides parallel and bottoms level, of equal weight, namely $30\frac{3}{4}$ oz., but the midship section of each varying as represented in the diagrams, were tested one with the other: first, to ascertain their speed; next, their stability; third, their lee-way; lastly, their burden or floating depth.



Midship sections; scale $\frac{1}{8}$ inch to 1 inch. The dotted line is the float-line.

The comparative velocities, as denoted by the balance-rod, were as follows:

Experiment 41.

No. 1 beat in speed No. 2 by 2 oz., that extra weight b

required in No. 1 to retard its speed till it equalled that of No. 2.

Experiment 42.

The speed of Nos. 2 and 3 proved equal.

Experiment 43.

The speed of No. 4 was the worst of them all, since it required 4 oz. extra weight to be put into No. 1, with which it was tested, before its speed equalled that of No. 4.

The inference to be drawn from the experiments is, that the curve gives greater speed than straight lines with angles. When the bottom of No. 4 had its angles cut off so as to form an ellipse, its speed was in consequence so far improved that 2 oz. in No. 1 were sufficient; or the velocity of No. 4 became equal to Nos. 2 and 3.

Of the stability and floating depth of the above four models,—

- No. 2. Stability equalled $3\frac{1}{2}$ oz. Floating depth $1\frac{1}{4}$ inch.
- No. 4. Stability equalled 3 oz. Floating depth $1\frac{1}{4}$ inch.
- No. 1. Stability equalled $2\frac{1}{4}$ oz. Floating depth $1\frac{3}{8}$ inch.
- No. 3. Stability equalled $1\frac{3}{4}$ oz. Floating depth 2 inches.
- No. 4. Ellipse equalled 3 oz. Floating depth $1\frac{1}{4}$ inch.

Here we have No. 2 possessing the greatest stability, and No. 3 the least, both being of the same speed. And again, No. 2 draws but 1 inch of water, whereas No. 3 draws 2 inches, or double, though of equal weight.

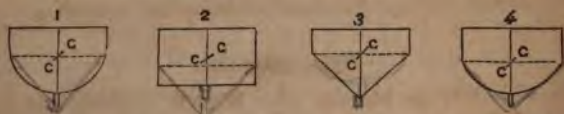
CHAPTER XI.

OF THE LEE-WAY, OR LATERAL RESISTANCE.

This property in a ship depends (see Experiment 5) directly upon the perpendicular depth at which it floats, and the length.

The following is a course of experiments relative to the lateral resistance of different midship sections or forms, and having reference to the depths of keels.

The midship forms selected for the experiments were those which had been employed in Chapter X., Experiments 41, &c. The diagrams are again given, but with the addition of keels to two of them. The results were measured by the length of lever, not by weights.



c, the centre of gravity, and the dotted lines the depth of flotation.

Experiment 44.

No. 1. Semicircular bottom . } Weight { Each with $\frac{1}{2}$ in.
No. 4. Elliptic bottom . . . } 1 lb. 13 oz. { depth of keel.

Result.—No. 1 resisted most, and equal to 1 inch of lever.

Experiment 45.

No. 1. Semicircular bottom . } Weight { Each with $\frac{1}{2}$ in.
No. 2. Flat bottom } 1 lb. 13 oz. { depth of keel.

Result.—No. 2 resisted most, and equal to $1\frac{1}{2}$ inch of lever.

Experiment 46.

No. 1. Semicircular bottom . } Weight { Each with $\frac{1}{2}$ in.
No. 3. V or Triangular bottom } 1 lb. 13 oz. { depth of keel.

Result.—No. 3 resisted most, and equal to 1 inch of lever, but was disposed to turn over.

Experiment 47.

No. 1. Semicircular bottom . } Weight { With $\frac{1}{2}$ in. keel
No. 4. Elliptic bottom . . . } 1 lb. 13 oz. { With 1 in. keel

Result.—No. 1 resisted most, and equal to 1 inch of lever.

Live? what length?

Experiment 48.

- | | | |
|----------------------------|----------------|------------------------------|
| 1. Semicircular bottom . } | Weight { | With $\frac{1}{2}$ in. keel. |
| 2. Flat bottom } | 1 lb. 13 oz. { | With 1 in. keel. |

ult.—No. 2 resisted most, and equal to $1\frac{1}{2}$ inch of lever. ?

Experiment 49.

- | | | |
|-----------------------------|----------------|------------------------------|
| 1. Semicircular bottom . } | Weight { | With $\frac{1}{2}$ in. keel. |
| 3. V or Triangular bottom } | 1 lb. 13 oz. { | With 1 in. keel. |

Result.—No. 3 was overturned by the resistance.

Experiment 50.

- | | | |
|----------------------------|----------------|-----------------------------|
| 1. Semicircular bottom . } | Weight { | Each with $\frac{1}{4}$ in. |
| 2. Flat bottom } | 1 lb. 13 oz. { | depth of keel. |

ult.—No. 2 resisted most, and equal to 3 inches of lever. ?

Experiment 51.

- | | | |
|----------------------------|----------------|-----------------------------|
| 1. Semicircular bottom . } | Weight { | Each with $\frac{1}{4}$ in. |
| 4. Elliptic bottom . . . } | 1 lb. 13 oz. { | depth of keel. |

result.—No. 1 resisted most, and equal to 1 inch of lever.

Experiment 52.

- | | | |
|-----------------------------|----------------|-----------------------------|
| 1. Semicircular bottom . } | Weight { | Each with $\frac{1}{4}$ in. |
| 3. V or Triangular bottom } | 1 lb. 13 oz. { | depth of keel. |

Result.—No. 3 resisted, but overturned.

Experiment 53.

- | | | |
|----------------------------|----------------|------------------------------|
| 1. Semicircular bottom . } | Weight { | With $\frac{1}{2}$ in. keel. |
| 2. Flat bottom } | 1 lb. 13 oz. { | With $\frac{1}{4}$ in. keel. |

result.—No. 2 resisted most, and equal to $1\frac{1}{2}$ inch of lever.

Experiment 54.

- | | | |
|-----------------------------|----------------|----------|
| 2. Flat bottom } | Weight { | No keel. |
| 3. V or Triangular bottom } | 1 lb. 13 oz. { | No keel. |

Result.—The resistance equal.

Experiment 55.

No. 1. Semicircular bottom . } Weight { No keel.
 No. 3. V or Triangular bottom } 1 lb. 13 oz. { No keel.

Result.—No. 3 resisted most, and equal to 4 inches of lever.

Experiment 56.

No. 3. V or Triangular bottom } Weight { No keel.
 No. 4. Elliptic bottom . . . } 1 lb. 13 oz. { No keel.

Result.—No. 3 resisted most, and equal to 6 inches of lever.

Experiment 57.

No. 1. Semicircular bottom . } Weight { With $\frac{1}{2}$ in. keel.
 No. 2. Flat bottom } 1 lb. 13 oz. { No keel.

Result.—No. 2 resisted most, and equal to $1\frac{1}{2}$ inch of lever.

Experiment 58.

No. 1. Semicircular bottom . } Weight { With 1 in. keel.
 No. 4. Elliptic bottom . . . } 1 lb. 13 oz. { With $\frac{1}{2}$ in. keel.

Result.—The resistance was equal, but No. 1 overturned,

*Observations on the Results of the Lateral Resistance of the
 Four Models.*

No. 1 resisted most with a depth of keel of $\frac{1}{2}$ inch.

No. 2 resisted most with a depth of keel of $\frac{1}{4}$ inch, $\frac{1}{2}$ inch, 1 inch, and no keel.

No. 3 resisted most with no keel.

No. 4 was beat in every instance when tested against either of the others with equal depth of keel; but was equal to No. 1 when that had 1 inch keel and No. 4 had $\frac{1}{2}$ inch keel.

Again—

No. 1 possessed the least resistance with 1 inch of keel.

No. 2. The variations in the depth of keel made no difference.

No. 3 had the least resistance with 1 inch of keel.

No. 4 had the least resistance with no keel.

The scale of superiority appears to be thus—

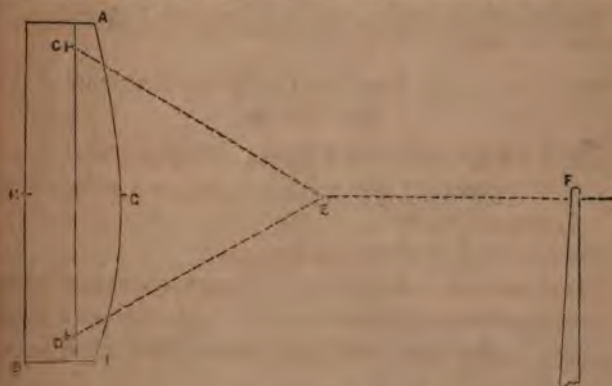
No. 2, the flat-bottomed, most decidedly the best, or 1.

No. 1, the semicircular-bottomed 2.

No. 4, the elliptic-bottomed 3.

No. 3, the triangular-bottomed, the most dangerous,
except with no keel 4.

On turning to the diagrams it will be seen that the centres of gravity of Nos. 2 and 4 are lower than those of Nos. 1 and 3. Again, the lines of flotation of Nos. 2 and 4 are likewise lower than Nos. 1 and 3. This being the case, the lateral leverage of Nos. 2 and 4 above the water is greater than that of the other two; and their leverage is, on the contrary, greatest in the water, particularly the triangular bottom. No. 2 floats higher than it would have done, had it not been made hollow in part to reduce its weight down to the others.

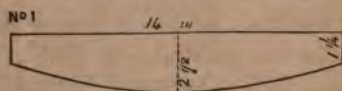


The mode by which the lateral resistance was tested will be clearest understood by the inspection of the accompanying diagram. *A B* represents the upper surface of the models, being 14 inches long and 4 inches wide at *a b*; *c* and *d* the

two nails to which the lines *CE*, and *DE*, were attached; is the single line fixed on the end of the balance-rod *F*. The sides of the models were rounded off as *AGI*, to prevent oscillation whilst being drawn through the water; at the same time, partaking more of the usual form of the sides of a ship.

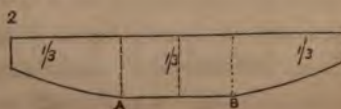
Whilst carrying out these experiments on lateral resistance and keels, many instances occurred of the superior effects of the lengthening of a keel, over the deepening of one. The deepening of a keel acts directly and powerfully to overturn a ship, not so the lengthening; and although a small addition of depth may and does, under certain circumstances, improve a ship's lateral resistance, yet if the depth be much increased it so militates against the object sought by the great inclination which ensues, consequent on the force of lateral resistance, as to be altogether injurious.

The next experiments were taken to ascertain the effects, regards speed, of curving up the bottoms of vessels from the midship or mid-length, to both head and stern as high as the load water-line; or commencing the same at one-third or one-fourth of the length of each, and leaving the middle one-third or one-fourth of each quite straight or uncurved.



Experiment 59.

A model 14 inches long, 4 inches wide, and $2\frac{1}{2}$ inches thickness, weight 30 oz.; curved from middle length to head and stern as No. 1.



Experiment 60.

The model No. 2, of the precise length, breadth, depth, and weight as No. 1, but having the bottom, *A B*, one-third of the length, quite level or straight.

*Experiment 61.*

The model No. 3, of the same dimensions, &c. as the preceding, but with the bottom, *A B*, left flat half of the length.

Result.

No. 1 beat in speed No. 2 by $1\frac{1}{4}$ oz. extra weight; No. 2 beat in speed No. 3 by 2 oz. extra weight; therefore No. 1 beat in speed No. 3 by $3\frac{1}{4}$ oz. extra weight.

Experiment 62.

This experiment was undertaken to ascertain what might be the advantage, as regards stability, by constructing a ship with projecting sides, instead of carrying them up perpendicularly.

Two models were made, each 15 inches long, $2\frac{1}{2}$ inches deep, with flat bottoms; but one of them 4 inches wide and perpendicular sides, the other being in width at the bottom at midships $3\frac{1}{2}$ inches, and across the top $4\frac{1}{2}$ inches, and making an angle from the perpendicular of 11° .

Sections of the models taken at the midships.



Scale, $\frac{1}{2}$ inch to 1 inch. Weight of each, 40 oz.

These models were first tested upon the water, each in solid wood, when the stability of each equalled 3 oz. But when a part of the upper insides of both the models was hollowed out, which reduced their respective weights to 33 oz., the stability of No. 1 equalled $3\frac{1}{2}$ oz., and that of No. 2, 3 oz. only.

Let it be observed, that before either of the models was lightened, No. 1 sank in the water $1\frac{1}{4}$ inch, and No. 2 $1\frac{3}{4}$ inch. After being lightened, No. 1 sank in the water $1\frac{1}{2}$ inch, and No. 2, $1\frac{1}{4}$ inch.

The result of lightening the weight of each model from the upper part was the lowering of their centres of gravity, which at once became apparent in No. 1, by its increased stability. But the same result did not follow in No. 2, because of the diminished width of the lower line of its flotation. This proves most clearly, that the mere lowering of the centre of gravity acts with far less effect, with respect to the increase of stability, than the widening of the beam, or preserving the same as in No. 1.

OF THE RUDDER.

The rudder is a flat frame-work of timber, ascending perpendicularly from the bottom of the keel to a distance above the surface of the water, sufficient to admit of a lever being fastened to it in nearly a horizontal position, to move the same either to the right or left; it being so attached to the stern-post by means of hooks and rides, or similar contrivances, as to admit of such lateral motion.

The purpose of the rudder is to alter the direct course of a vessel when its body is going through the water, and into any position the helmsman may desire. That the rudder may act with full effect, it is necessary for the water to have as direct and unimpeded a course against either of its sides as it is possible to allow. The wider the body of the rudder is made, the

greater the power; but in general it does not much exceed in sailing vessels one twenty-eighth part of a ship's length.

OF THE KEEL.

The keel is that part of a boat or ship which is situated at the bottom on the outside, and extends in a direct line from the cutwater at the head to the post at the stern, descending perpendicularly down below the hull to the depth of several inches or feet, according to the size of the vessel. Its uses are, —first, to cause the floating body, say of a ship, to preserve a direct course in its passage through the water; second, to act as a check to lee-way; third, to moderate the rolling motion.

Ships formed with flat bottoms, and particularly if they be constructed with parallel sides, require little depth of keel to preserve a direct course; and in order to check the lee-way, a substitute for a keel is applied in the form of a sliding keel (called lee-board), suspended over the lee-side, as seen in barges. But when the bottoms of vessels are not flat, or do not draw the same depth of water at the head and stern, particularly the latter, the keel becomes more essential, or the ship will have a rotatory motion and be under no command.

With regard to the depths of keels, it will be needless to repeat what has already been given in the experiments, from 48 to 58.

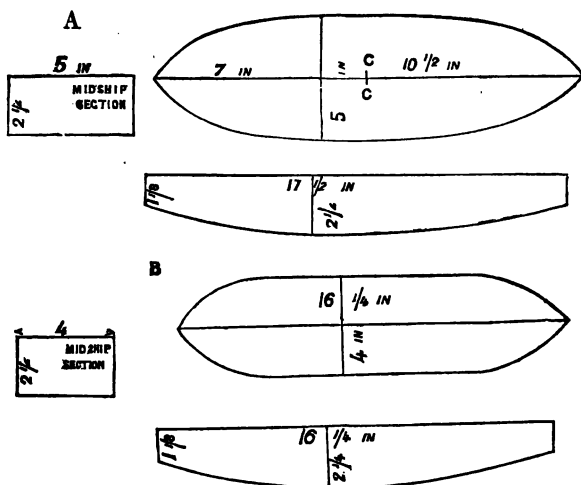
CHAPTER XII.

Having terminated the experiments relating to the midship section, and lee-way or lateral resistance, it will not be departing from the subject in view, to introduce in this place a

few examples of floating bodies varied in their dimensions, and to compare their respective speeds.

First.

Diagram A, a boat 5 inches wide, $17\frac{1}{2}$ inches long, having curvilinear sides; weight, 25 oz.; compared in speed with B, a boat 4 inches wide, $16\frac{1}{4}$ inches long, with parallel sides; weight, 25 oz. Both these boats had their bottoms curved upwards from their midship sections to their load water-lines.



Experiment 63.

The boat A beat B in speed by 6 oz. additional weight, that is to say, to cause the speed of both to be equal under the same drawing force. The stability of A equalled 5 oz.; that of B, 3 oz.

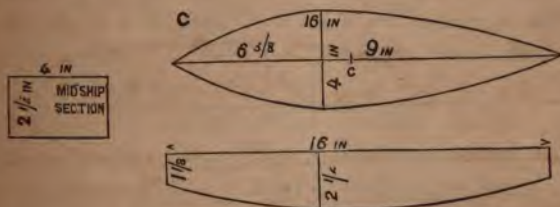
Second.—Experiment 64.

The boat A compared in speed with a boat C, after the

form of a bird, being 4 inches wide at midship, 16 inches long, having its bottom curved up the same as A, and of equal weight, being 25 oz. The boats A and C were equal in speed. The stability of A equalled 5 oz. ; that of C, 2 oz.

Experiment 65.

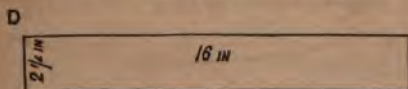
But when C had the angles between the bottom and sides removed and smoothed down, C then beat A by 4 oz. extra



weight. But the stability was, in consequence, reduced from 2 oz. to $1\frac{3}{4}$ oz.

Third.—Experiment 66.

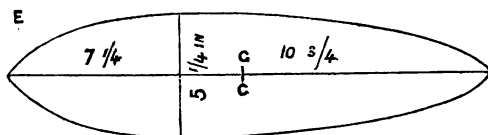
The boat C was compared in speed with a boat of the precise form, but with the bottom not cut up, being left flat as in the diagram D ; the weights equal, and being in this



instance 22 oz. The boat C beat D by 12 oz. extra weight. Stability of C equalled 2 oz., and that of D, 2 oz.

Fourth.—Experiment 67.

The boat A was tested in speed with a boat E, $5\frac{1}{4}$ inches wide, 18 inches long, with curved sides, and bottom curved the same as A. Their weights being first made to correspond,



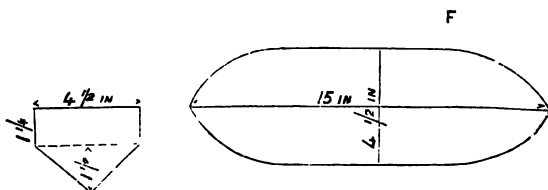
the trial upon the water gave their speeds equal. The stability of E was $5\frac{1}{4}$ oz.

Experiment 68.

Upon the removal of the lower angles of the boat making all smooth, its speed was improved 4 oz., so that it beat A by the sum of 4 oz.

Fifth.—Experiment 69.

The parallel-sided boat B, being tested against a parallel-sided boat F, with triangular form of midship section, in width $4\frac{1}{2}$ inches, and in length 15 inches, with the weight of $21\frac{1}{2}$ oz.; the form of bows the same: being attached to two arms of the balance-rod, and drawn through the water, the result gave 4 oz. in favour of B; that is, the additional weight of 4 oz. was put into B, which then rendered the speeds equal.

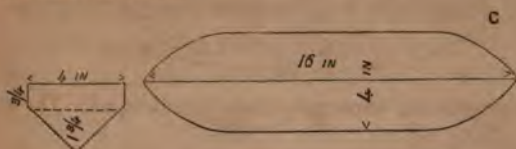


This was not a fair trial, F being wider and shorter than B. The stability of F equalled $2\frac{1}{2}$ oz.

Sixth.—Experiment 70.

The boat B was again tested with another boat G, the midship section being a triangle; the length and breadth

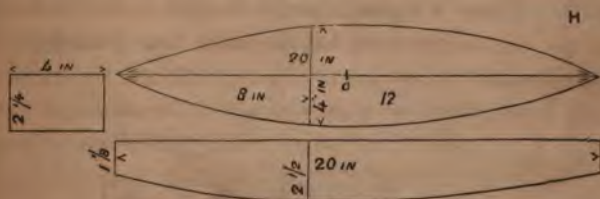
same as B, and weight equal, being $21\frac{1}{2}$ oz., and having the bows of the same form.



The trial gave 8 oz. in favour of B, since the superior speed of B required that weight extra to retard it to an equality with G. The stability of G equalled $1\frac{1}{4}$ oz. The boat B drew $\frac{7}{8}$ inch water at midship, F drew $\frac{3}{4}$ inch, and G drew $\frac{7}{8}$ inch; the respective weight of each being the same.

Seventh.—Experiment 71.

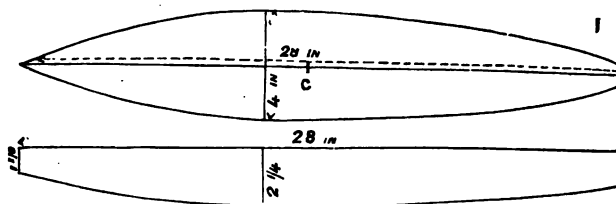
The boat C being compared in speed with a boat H, of the same weight, and width of 4 inches; but in length 20 inches, having the bottom curved up as C.



The boat H beat the boat C by 12 oz.; H requiring that additional weight to equalize their speed. The stability of H was $2\frac{1}{4}$ oz.

Eighth.—Experiment 72.

The boat H was compared in speed with a boat I, of the same weight, namely, 33 oz., and width of 4 inches, but 28 inches long, having the bottom curved as H.



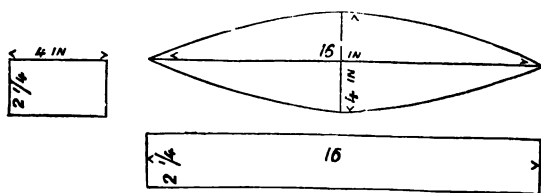
The trial gave the speed on the side of the boat I, and equal in weight to 24 oz. extra. The stability of I was $2\frac{1}{4}$ oz.

Ninth.—Experiment 73.

The boat I beat the boat E, before the angles were removed by 32 oz. The stability of I was $2\frac{1}{2}$ oz., and that of $5\frac{1}{4}$ oz.

Tenth.—Experiment 74.

A boat K, 4 inches wide and 16 inches long, having midship section at the point of half its length, with the bow and stern alike, was tested against the boat C, but with both not curved up. The weight of each $20\frac{1}{2}$ oz.

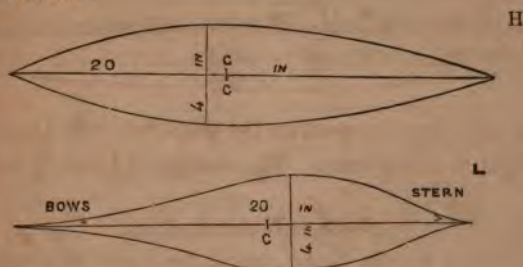


The boat K beat in speed the boat C by 2 oz., but its course through the water was much inferior to C, therefore a piece of keel was necessary to remedy the evil. The stability of K equalled $2\frac{1}{4}$ oz.; that of C, 2 oz.

Eleventh.—Experiment 75.

The bird-shaped boat H, being 20 inches long and 4 inches

, but not curved at the bottom towards each end, being straight, was tested against a boat of the form marked the length, width, and weight the same as H, which weighed 22 oz.



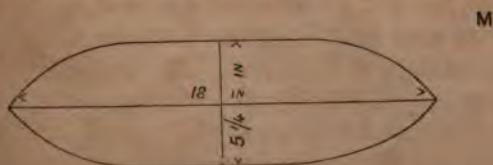
The trial of these two boats gave the speed on the side of H, with its bottom not curved, and to the amount of 4 oz. in weight when the boat L was drawn with its stern foremost; but when tested with its bows foremost, no difference perceptible between them in speed. The stability of H was $2\frac{1}{4}$ oz.; that of L, $1\frac{1}{4}$ oz.

Experiment 76.

On comparing the speed of H, with its bottom curved up, with the boat L, the difference was 12 oz. on the side of H, it being so far superior to L.

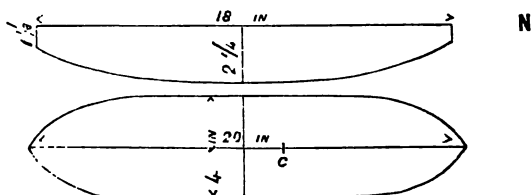
Twelfth.—Experiment 77.

Two boats, one of them, M, after the form of E, being 18 inches long, a trifle more than $5\frac{1}{4}$ inches wide, and which



It was in this instance situated at the mid-length, with the

bottom curved up to the load water-line, commencing from middle length, and terminating at each extremity; weight $2\frac{1}{2}$ lbs. The other boat, N, 20 inches long, and a trifle more than 4 inches wide, sides parallel, but the bows the same as both, weight equal to M. This boat was also curved up at the mid-length to each extremity.



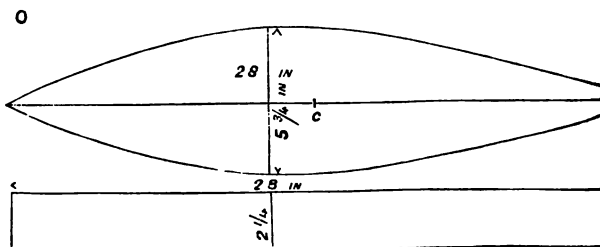
The result, upon trial, gave the speed 3 oz. superior on side of M. The stability of M equalled 6 oz.; that of 4 oz.

Experiment 78.

When the boat H was tested with the parallel-sided boat N, their respective weights being 2 lbs. 7 oz., the boat H beat the boat N in speed by the extra weight of 16 oz. The stability of H equalled $2\frac{1}{4}$ oz.; that of N, 4 oz.

Thirteenth.—Experiment 79.

A boat O, of the bird shape, $5\frac{3}{4}$ inches wide, 28 inches long, weight 2 lbs. 5 oz., was tested in its speed again

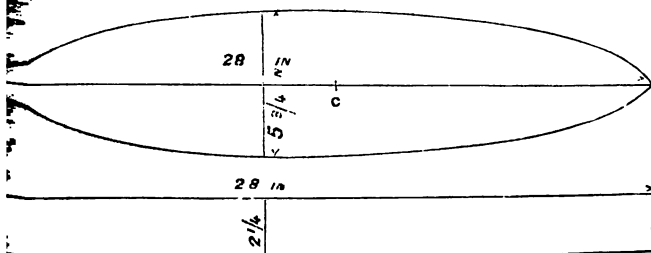


at also of the bird shape, 4 inches wide, 28 inches long; weight, 2 lbs. 5 oz., and denoted in the preceding diagrams by the letter I. I sank in the water $\frac{1}{16}$ inch, and O sank $\frac{1}{16}$ inch.

The result gave the speed on the side of I, in the extra weight of 21 oz. The stability of O was 8 oz.; that of I, 12 oz.

Fourteenth.—Experiment 80.

The boat O was tested with a boat P, of a different form, but of the same width of $5\frac{3}{4}$ inches, 28 inches long; and weight of each, 3 lbs. 4 oz. O sank in the water $\frac{1}{16}$ inch, and P sank $\frac{3}{4}$ inch.

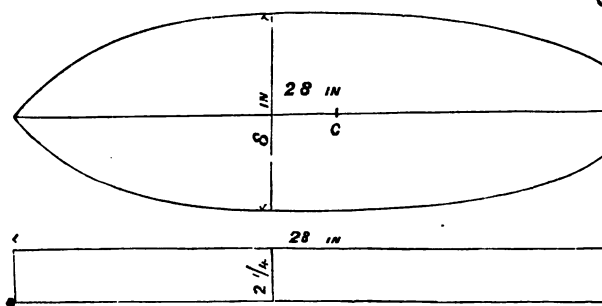


The boat O beat P by 2 lbs. 5 oz. extra weight. The stability of O equalled $8\frac{1}{2}$ oz.; that of P, 12 oz.

Fifteenth.—Experiment 81.

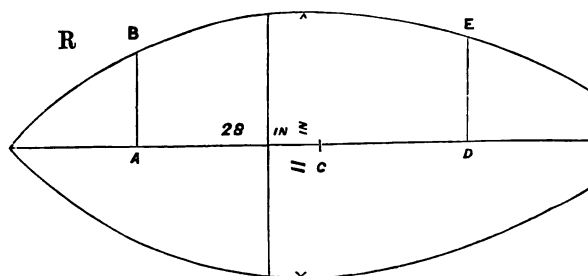
The boat P was tested against the boat Q, being 8 inches wide, 28 inches long, and weight of each 3 lbs. 4 oz. P sank in the water $\frac{6}{8}$ inch, and Q sank $\frac{5}{8}$ inch.

The boat P beat Q by 20 oz. extra weight. The stability of P equalled 12 oz.; that of Q, 21 oz.



Sixteenth.—Experiment 82.

The boat Q was tested against the boat R, being 11 i wide, 28 inches long, of the bird or duck shape, each wei 5 lbs. 1 oz. Q sank in the water $\frac{1}{16}$ inch, and R $\frac{1}{8}$ inch.



The boat Q beat the boat R by 4 oz. extra weight. stability of Q was 25 oz. ; that of R, 29 oz.

Seventeenth.—Experiment 83.

The boat Q was again tested with a boat T, of simi mensions, being 8 inches wide, 28 inches long, but

weighing 4 lbs. 6 oz. Q sank in the water $\frac{13}{16}$ inch, and T sunk $\frac{7}{8}$ inch.

The boat T beat the boat Q in speed by 32 oz. extra weight. The stability of T equalled 16 oz.; that of Q, 4 oz. See diagram at the end.

Experiment 84.

This experiment was made to ascertain the law of the density of water with respect to bodies floating upon its surface, and the displacement they occasion. A tin vessel of a square form, and measuring 4 inches cube, was put on the water; and having first noted the displacement by its own weight, 2 oz. were then put into it, when their displacement was carefully marked upon one of the sides of the vessel. Another 2 oz. being added, the displacement was again marked; and so on to a third, &c., &c., up to 16 oz., altogether making, in the whole, eight divisions. Upon measuring the several divisions recorded, they were found all equal; consequently, showing that equal weights caused equal displacements. This law applies only to bodies floating upon and near the surface.

CHAPTER XIII.

Having completed some of the most necessary experiments relative to ships, as a supply of materials for the foundation of the superstructure, a brief recapitulation of the conclusions, before entering upon the construction of a boat or ship upon the principles proved essential to be observed, will, it is considered, simplify proceedings, and therefore be next entered upon.

Of the Resistance of Water against the Head of a Vessel.

—With a square and perpendicular bow, the resistance is directly as the surface.

Of Weight—its Effects when placed in a Body floating in Water.—The resistance of water against any increase of weight is directly as the weight.

Of Lateral Resistance.—The centre of lateral resistance is exactly at the mid-length point of the keel of a ship when floating level, and at rest, but not otherwise; for when in motion, the head or bow meeting with greater resistance from the water than any other parts, the centre of lateral resistance will be moved proportionately forward.

Stability.—This acts when the width is increased one-half nearly in the cubic ratio, but not afterwards, being as 2³ : 14, 22 : and when the length is added to, the law of stability, if the dimensions be doubled, operates in the proportion of 1 : 3; then, the same quantity of length being continually annexed, it takes the arithmetic ratio. Again, the height or thickness of a body being alone varied, the law of stability operates most when the depth, measured from the line of flotation on the parallel-sided body, equals one-fifth of the width, the centre of its gravity being on a level with the surface of the water.

The Form of the Bows.—The conclusions are, that the sharper the form of the bows, the less is the resistance from the water; and if gentle horizontal curves be substituted for the horizontal straight lines on the sides of the bows, the speed will be improved.

The Bevelling-up of the Bows.—The effect of the bevelling up of the bows is in favour of speed by diminishing the resistance.

The Bevelling-up of the Stern.—The tapering of the stern throughout the greater length of the body of a ship is detrimental to speed; but if it be commenced at the midship

tion, and the reduction moderate and a curve, the advantage will be great. The same benefit results when the bottom is gently curved up from the midship to the stern.

Of the Length of Ships, all having the same Bows and Beam, and equal in Weight.—The result obtained is,—if equal increment of length be tested, equal advantages will be obtained on the side of the equal increments.

The Form of the Midship Section.—As regards speed, the semicircular form possesses the most, and the triangular one the least. Again, the flat-bottom floats the shallowest, and the triangle the deepest, being double that of the former when of equal weight.

Lee-way.—This property in a ship depends directly upon its perpendicular depth and length at which it is immersed whilst floating upon the water.

Of Floating Bodies varied in their Dimensions.—It appears that the shallower the same weight can be supported upon water, the less the resistance as regards speed; consequently extended surface of bearing to a certain degree is advantageous towards facilitating progress, and which a moderate curve always imparts. But where an extension of surface-bearing can be obtained without loss of speed, stability becomes directly increased, which is a gain in power to vessels impelled forward by the wind, as it admits of a proportionate increase in the breadth of sail, and therefore of speed.

Whilst carrying out these particular experiments, it appeared, that if the angles exposed in any way to the water were rounded off, greater speed ensued; but it was generally at the expense of stability, and decidedly so if the projections be low, because the greater is the length of lever from the centre of motion.

Curves were found to favour speed in comparison with straight lines; consequently the latter are to be avoided as

much as possible wherever speed is the object, and the sails and steam are to be the moving powers.

With respect to the general form of ships, experiment decides most positively that the bird or duck species affords the true models for comparison and study, since the forms of fish are so exceedingly various.

CHAPTER XIV.

Much has been said upon the comparative speed of several models, likewise of their stability. Now, as stability forms the basis of the power by which the wind, acting upon sails, impels forward the body of a vessel, it will be right to take into consideration and calculation these respective qualifications, as possessed by some few of the models which have been tested. It is evident that those models which equalled or surpassed their competitors in speed, and at the same time had greater stability, will always, under the same weight, run away from vessels of less stability; and if this be admitted, it will be necessary only to investigate the more extreme cases of both speed and stability, with the exception of one or two instances, when the merits of all the rest follow as a matter of course.

From what has been already ascertained, it appears that when two models are of equal weight and similar outline, but one longer than the other, the former invariably has the advantage in speed; consequently, in the following investigations, the calculations had best be confined to models of the same length, but varying in their dimensions of breadth; the weights when tested against each other being always made equal.

Since the models of 28 inches in length are the largest

which have been employed, and from their variety of form, though only few in number, they may in fairness be selected for the requisite calculations.

First.—Let the model I, in Experiment 72, be selected, which is of the bird or wild-fowl shape, 4 inches wide and 28 inches long. This, when tested with the model O, in Experiment 79, also of the bird form, whose breadth is $5\frac{3}{4}$ inches, length 28 inches, and the weight 2 lbs. 5 oz., gave the following result: the model I beat in speed the model O by 21 oz. extra weight. The stability of I equalled $2\frac{1}{2}$ oz., and that of O, 8 oz.

Now the 21 oz. extra weight may be called nearly half of the whole weight moved, being 2 lbs. 5 oz. The stability of I, which represents the power of carrying sail, is superior to that of O, in the proportion of 32 : 10, or 3 : 1; therefore say 10, which is 74 oz. over and above the model I. This sum is to be set against the one-third of the extra weight of 21 oz., or 7 oz., the speed of I, and gives the balance of speed, the sails of each being proportional to their respective stabilities, greatly on the side of O, and equal in ounces to $74 - 21$, or 53 oz.

The draught in the water of these models, each laden with the extra 21 oz., making 49 oz., was in the model I, $1\frac{1}{8}$ inch deep, and in O, $\frac{3}{4}$ inch; thus proving the boat with greater breadth of beam would, under canvas, be decidedly the better of the two.

Second.—The next models for comparison are O and P, in Experiment 80. These were both $5\frac{3}{4}$ inches wide, 28 inches long, and each of the weight of 3 lbs. 4 oz. In this instance, O proved superior in speed to P by 2 lbs. 5 oz. extra weight. The stability of O now equalled $8\frac{1}{2}$ oz., and that of P 12 oz. The extra weight of 37 oz. equalled, say two-thirds of the weight moved.

The stability of P is not quite one-half more than that of O.

but let it be so, which sum, if denoted by ounces, will equal 26 oz., and this set against the 37 oz., the extra speed weight of O, will give the superior speed. When both placed under sails proportionate to their respective stability to the model O, and in ounces equal to $37 - 26 = 11$ (meaning when P and O are moving under sail with the speeds equal, O will carry at the same time 11 oz. more than P.

The draught in the water of these two models, when equal weight, and each having the extra 37 oz., or total 74 oz., was in O $1\frac{1}{8}$ inch, and in P $\frac{7}{8}$ inch.

Third.—The model P again made use of to test the model Q, in Experiment 81. The dimensions, &c. of P are, width $5\frac{3}{4}$ inches, length 28 inches, weight made equal to 3 lbs. 4 oz. The dimensions of Q are, width 8 inches, length 28 inches, weight 3 lbs. 4 oz. The result, as stated in Experiment 81, was 20 oz., which P carried extra to cause its speed to equal with the model Q. The stability of P equalled 12 oz. and that of Q, 21 oz. The extra weight of 20 oz. is two-fifths of 52 oz., the weight of the model. The stability of Q is one and three-quarters of P, or above that of P by three-fourths of 52, which, when reduced to ounces, will be 39, and against the two-fifths of the extra weight or 20 oz., will give the balance of speed on the side of Q, equal to 19 oz.

These two models, P and Q, sank in the water when each was loaded with the additional weight of 20 oz., or total 72 oz. viz. P $\frac{7}{8}$ inch, and Q 1 inch.

The conclusion arrived at is, the superior stability of Q enables it to have the advantage in speed over P, each carrying sail proportionate to their stabilities.

Fourth.—From the marked speed of O over P, it will be right to compare its qualities with those exhibited in Q. It has been already shown that the speed of O beat the speed

by 37 oz., and P beat Q by 20 oz.; therefore it will require the sum of the two, or $37 + 20 = 57$ oz. extra weight placed on O to retard its speed till it equals that of Q. The weight of O, as before given, equalled 52 oz.; therefore the extra weight of 57 oz. exceeds it by 5 oz. The stability of O equalled $8\frac{1}{2}$ oz., and that of Q 21 oz., without the 57 oz. extra. From the above it appears that O has the advantage in speed equal to more than the weight moved; and Q has the excess of stability above O equal to one and a half its stability; which being reckoned in ounces equals $52 + 26 = 78$ oz.; and the extra weight of 57 oz., when taken from 78 oz., leaves 21 oz. in favour of Q, the model with the greatest breadth of beam.

The depth or draught in the water of the models when under the double extra weight of $37 + 20$, or 57 oz., making the total weight of each 109 oz., was in model O, $1\frac{5}{8}$ inch, and in Q, $1\frac{1}{8}$ inch. The model Q, from its great breadth of beam, would beat the model O, provided, as before mentioned, in the preceding cases, the surface of the canvas be proportionate to their stabilities.

Fifth.—In Experiment 82, the model Q was tested against

The dimensions of Q are 8 inches in width, 28 inches in length, and the weight 5 lbs. 1 oz.; and those of R, 11 inches in width, 28 inches long, and weight 5 lbs. 1 oz. also. Likewise, it is there shown the model Q beat in speed the model R by 4 oz. extra weight. The stability of Q equalled 24 oz., and that of R, 29 oz.

The extra weight of 4 oz. is one-twentieth of 81 oz., and the stability of R exceeded that of Q by 5 oz., which is rather more than one-fifth of 24; and, estimated in ounces, will, in 24 oz., the weight moved, equal 16 oz.; and, minus the 4 oz. extra weight, the measure of the superior speed of Q, leave 20 oz. as the advantage, ultimately, of R over Q. Admitting

the above to be correct, then R, under sail, and of equal weight with Q, will beat that, or any other of the same length, but having the beam of less dimensions. The two models Q and R sank in the water $\frac{7}{8}$ inch when of the same weight and with the addition of the 4 oz. extra, or total 85 oz.

Sixth.—In Experiment 83, the model Q was tested against T, the dimensions of these two boats being the same in width, length, and weight. The result of their speeds is also denoted—that T beat Q by 32 oz. The stability of T equalled 16 oz., and that of Q, 23 oz.

Therefore Q has more stability than T by nearly one-half, being 7 oz., which, if put in ounces, equals $30\frac{1}{2}$ oz. But the extra speed of T was 32 oz.; and, taking $30\frac{1}{2}$ oz., or $32 - 30\frac{1}{2}$, leaves the sum of $1\frac{1}{2}$ oz. on the side of T, which would in consequence, under equal weight and sails proportionate to their stabilities, beat Q by the said extra weight of $1\frac{1}{2}$ oz. The models Q and T sank into the water when of the same weight, thus: Q sank $\frac{1}{16}$ inch, and T sank $1\frac{1}{16}$ inch.

The inference which may be drawn from these calculations is, that Q, if lengthened, would beat R; and R, if made longer than Q, would again beat Q. Moreover, if a model, say S, be made of the same proportional length and breadth of R, before lengthened, meaning the breadth at the midship to be two-fifths of the length, but the length of S to equal the length of R, increased, the breadth of S will then exceed the breadth of R, whose length alone had been added to, and therefore would be beaten by S.

CHAPTER XV.

It has been seen in the investigations of the preceding Chapter, that when any two of these models were of equal

weight and equal length, the one with the greatest breadth of beam beat the other. In the Experiments on Stability numbered 8, and Scale C, it is shown, that when the thickness or depth of flotation is varied, the breadth and length being preserved constant, the greatest stability exists at one-fifth of the beam.

Now, it has been before mentioned in the last Chapter relative to the depths of the lines of flotation, that in some instances, as in Experiment 80, in I, it exceeded the one-fifth; and in others, as in Experiments 81, 82, it was less. Upon testing a few of the models between one-fifth and one-fourth for the line of flotation, the following proved to be the case.

With the models I and O, each having their lines of flotation situated between the one-fifth and one-fourth, which in the model I equals $\frac{3}{8}$ inch, and in O equals $1\frac{3}{8}$ inch, at this depth the weight of I was required to be increased until it altogether equalled $39\frac{1}{2}$ oz., and model O equalled 78 oz.

In the Experiment No. 80, the models I and O being then of equal weight, the speed of I beat the speed of O by 21 oz. Under the present circumstances, O exceeds the weight of I by 39 oz.; therefore I has the advantage over O of 21 oz. and 39 oz., or together 60 oz. With respect to the stability possessed by these two models, I and O, it was found upon trial that I in stability equalled $2\frac{1}{2}$ oz., and O equalled $8\frac{1}{2}$ oz., showing O to have 6 oz., or two stabilities above I, which in weight equals 78 oz.; but take away the 60 oz., and there remain 18 oz. in favour of the model O, when under sail.

Likewise, in the same Chapter, it is stated of the models O and Q, that when of equal weight, O beat Q by 64 oz. extra weight. Upon causing the model O to sink in the water until its load-line was between one-fifth and one-fourth, it required an increase of its weight, as before given, up to 78 oz.; and

water line $\frac{1}{5}$ from bottom of map

Q to equal 152 oz. The stability which each now possesses was in O $8\frac{1}{2}$ oz., and Q 32 oz.—that is to say, the model possesses (let it be granted) two and a half stabilities as the model O, or in oz. $78 + 78 + 39 = 195$. How from this sum must be taken the extra weight of Q above which is 74 oz., together with the 64 oz. the extra weight speed, and equalling 138 oz.; or $195 - 138 = 57$ oz., which number of ounces is on the side of Q, when under sail proportionate to its stability.

Again, with regard to the models Q and R: when of equal weight, Q beat R in speed by 4 oz. extra weight. It has been mentioned before of the model Q, when the line of flotation was made one-fifth and one-fourth of the beam, that it required the whole weight to be 152 oz. The model R, in similarly circumstanced, required its whole weight to amount to 292 oz.; and the stabilities of these two models was in Q equal to 32 oz., and in R, 42 oz.: therefore, in the present instance, R has one-third of a stability above Q, which one-third of ounces equals $152 \div 3 = 50$; but from this sum the extra weight of R above Q must be deducted. Now the weight of R equals 292 oz., and that of Q 152; then $292 - 152$ equals 140 oz., which, with the 4 oz. representing the speed advantage above R, comes to 144 oz. The superior stability of R has been shown to be 50 oz.; therefore $144 - 50 = 94$ oz. which Q beat R in speed.

From the above result it is clear that for the model R to beat in speed the model Q, it will be necessary to place the line of flotation considerably lower than one-fifth, so as to materially lighten the whole weight of R. But upon taking out 96 oz. from R, thus leaving 196 out of 292 oz., the stability of Q, as before, equals 32 oz., and that of R equals 34 oz.; and R sank in the water with the reduced weight down to $1\frac{1}{16}$ inch, and Q also to $1\frac{1}{16}$ inch. The difference in

present stabilities is 2 oz. for R, which in ounces = $152 \div 32 = 4\frac{2}{3}$ for each ounce; and, therefore, the 2 oz. of greater stability = 9 oz.; and being taken from 196, or $196 - 9 = 187$, and $187 - 152 = 35$ oz. of speed against R.

Again, after lightening the model R until it equalled in its whole weight 152 oz., the same as the model Q, the stability of R was now tried, and found to equal 32 oz., equalling that of Q; and R sank only to $1\frac{3}{8}$ inch.

It has been previously mentioned that Q beat R in speed when they were of the same weight, by 4 oz.; consequently, their stabilities being now the same, Q will, under sail, again beat R. Before, however, the result was quite contrary, as R by its superior stability beat Q. This being the case, it then appears, that for R again to beat Q, more weight must be removed out of R; that is to say, until it is of the same precise weight as it was, (as in Experiment 83,) namely, 81 oz. instead of 152 oz.

When the models Q and T were made to sink down into the water to the depth of between one-fourth and one-fifth of their midship breadth, the weight was required to be increased till it amounted in the total of the model Q, as before given, to = 152 oz., and that of T to = 140 oz.

In consequence of the above additional weight, the stability of T equalled 18 oz., and that of Q, 32 oz.

It appears then from these stabilities, that the model Q has the advantage over T to the amount of three-fourths of a stability, and which, if put into ounces, equals 105, the stability and weight of T. Q exceeds T in weight by $152 - 140 = 12$ oz.; but the extra speed of T over Q = 32 oz., which sum must be deducted also; then Q beats T in speed, when both are under sail, by the number of $105 - 12 + 32 = 61$ oz.

I.—Table of the difference of the Speed between the Models when towed through the Water.

Model.	Shape.	Beam.	Weight.	Result.
		Inches.	Ounces.	
I }	Bird	4	37	} O beaten by 21
O }	Bird	5 $\frac{1}{2}$	37	
O }	Bird	5 $\frac{1}{2}$	52	} P beaten by 27
P }	Oblong	5 $\frac{1}{2}$	52	
P }	Oblong	5 $\frac{1}{2}$	52	} Q beaten by 30
Q }	Oblong	8	52	
O }	Bird	5 $\frac{1}{2}$	52	} Q beaten by 64
Q }	Oblong	8	52	
Q }	Oblong	8	81	} R beaten by 4
R }	Bird	11	81	
Q }	Oblong	8	70	} Q beaten by 32
T }	Bird	8	70	

I is the swiftest, O the second, T the third—all of the shape.

II.—Table of the difference of Speed between the Six A when considered under sail proportional to their stability and carrying a light load.

Model.	Shape.	Beam.	Weight.	Depth.	Stability.	Result.
		Inches.	Ounces.	Inches.	Ounces.	
I }	Bird	4	37	0 15-16	2 $\frac{1}{2}$	} I beaten by
O }	Bird	5 $\frac{1}{2}$	37	0 11-16	8	
O }	Bird	5 $\frac{1}{2}$	52	0 15-16	8 $\frac{1}{2}$	} P beaten by
P }	Oblong	5 $\frac{1}{2}$	52	0 6-8	12	
P }	Oblong	5 $\frac{1}{2}$	52	0 6-8	12	} P beaten by
Q }	Oblong	8	52	0 5-8	21	
O }	Bird	5 $\frac{1}{2}$	52	0 15-16	8 $\frac{1}{2}$	} O beaten by
Q }	Oblong	8	52	0 5-8	21	
Q }	Oblong	8	81	0 7-8	24	} Q beaten by
R }	Bird	11	81	0 13-16	29	
Q }	Oblong	8	70	0 13-16	23	} Q beaten by
T }	Bird	8	70	0 7-8	16	

The model R is the swiftest under sail with the light T the second, and Q the third; Q being of oblong R and T of the bird shape.

III.—*Table of the difference of Speed between the Models when supposed to be under sail proportionate to their stabilities, and so loaded as to draw between one-fourth and one-fifth of their Beams deep in the Water.*

Model.	Shape.	Beam.	Weight.	Depth.	Stability.	Result.
		Inches.	Ounces.	Inches.	Ounces.	
I }	Bird	4	39½	0 7-8	2½	} I beaten by 18 oz.
O }	Bird	5½	78	1 3-8	8½	
O }	Bird	5½	78	1 3-8	8½	} O beaten by 57 oz.
Q }	Oblong	8	152	1 13-16	32	
Q }	Oblong	8	152	1 13-16	32	} R beaten by 94 oz.
R }	Bird	11	292	2 1-2	42	
Q }	Oblong	8	152	1 13-16	32	} R beaten by 35 oz.
R }	Bird	11	196	1 5-8	34	
Q }	Oblong	8	152	1 13-16	32	} T beaten by 61 oz.
T }	Bird	8	140	1 13-16	18	
O }	Bird	5½	78	1 3-8	8½	} P beaten by 6 oz.
P }	Oblong	5½	84	1 3-8	12	

The model Q is the swiftest under sail, when full loaded, and O the second; the oblong, in this instance, being the best.

IV.—*Table showing the proportion of the Beam the depth of Flotation ought to be for the greater Speed, with Bottoms quite flat, and impelled forward by the Wind on Sails proportioned to their stability.*

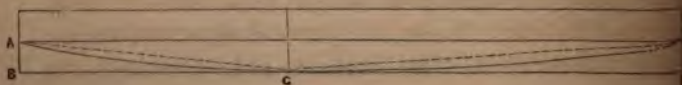
Model.	Shape.	Beam.	Weight.	Depth.	Stability	Proportion of Depth to the Beam.	Proportion of Beam to the Length.
		In.	Ounces.	Inches.	Ounces.		
O	Bird	5½	50	0 7-8	8½	One-Seventh	5
Q	Oblong	8	152	1 13-16	32	One-Fourth	3½
R	Bird	11	81	0 13-16	29	One-Fourteenth	2½
T	Bird	8	70	0 7-8	16	One-Ninth	3½
I	Bird	4	20	0 9-16	2½	One-Seventh	7

Upon a review of these Tables it will be seen, that a maximum of weight and speed is incident to some forms of the models, and not to others. This circumstance is most apparent in the long bird or fish shapes, since their stabilities

cease to increase with additional weight, after it amounts to a certain quantity; that quantity, therefore, may be denominated the limit or maximum. But with the oblong model Q, and the duck-shaped model R, any increase of their weight is attended with an increase of their stability also. However, it is seen of the model Q, that with the increased stability, consequent on the additional weight, the speed is not so retarded by it as in the case of the model R and the other models; therefore advantage can be taken of this peculiarity for all ships intended for burthen.

CHAPTER XVI.

The six models just treated of were all with flat bottoms, and this for the sake of convenience. The forms calculated for service must have the curve along the bottom, as shown to be so necessary in Experiments 33 to 36. They must have likewise the keel deeper towards and at the stern than towards and at the stem (see Experiment 5): again, the space between the curve along the bottom and the keel must be filled up at both stem and stern, and so constructed as to offer at the bows, from the cutwater to the midship, the least resistance possible to the water; and from the midship to the stern-post, to afford the easiest and most direct passage for the water, that it may act to the best advantage against the sides of the rudder.



Upon an inspection of the accompanying diagram, it will be seen that the part cut off the flat bottom by the curve AC

equals nearly the triangles ABC and CDE ; but since a portion of the triangles will be made up by the sharp bows and body situated between the keel and the line of curvature along the bottom, it will occupy the space of about half the cubic parallelogram; therefore a quarter part only will be necessary to add to the depth at the midship section for the load-line of flotation. Upon testing the above by two models, one with a flat bottom, the other curved and yet left filled up, as required between the curve and the keel, the displacement in the water gave a quarter part as the exact difference. This proportion of a quarter part to be added to the depth at midship, applies to all the six models, from their similarity in flatness; therefore the depth at their midship section for their load water-line should be increased by one-quarter part of their draught, when having a flat bottom at midship.

On turning back to those experiments which relate to the depths of keels, commencing with No. 44, it will be seen that the flat-bottomed model (No. 2) required no keel; likewise the triangular midship model No. 3; but to the forms Nos. 1 and 4, keels were necessary.

Before deciding upon the midship section best calculated for service, it will be right to criticise those sections which have been already tested. To this end, it will be advisable to review the Experiment 41, where it appears of the triangular model No. 3, that its speed equalled Nos. 2 and 4, the latter having been previously made elliptic. In lateral resistance, No. 3 possessed the same as No. 2, Experiment 54. In stability, No. 3 proved the worst of the four (see Experiment and Table, &c. after No. 43). Lastly, in depth or draught, No. 3 again exceeds all the others. The conclusion to be drawn from the preceding facts is of such a nature as to justify the rejection of the triangular form of midship.

The semicircular form of midship (No. 1) possessed speed as

one good quality; but which advantage is counterbalanced, first, by its circular outline being conducive to rolling; next, the depth at which it floats; and third, its deficiency in stability. These evils, it must be admitted, are highly objectionable and warrant the rejection of the semicircular midship section, except where speed only is sought, when the employment of iron or lead ballast can be had recourse to as a corrective of its instability.

There remains to be considered the flat-bottomed model No. 2, and the elliptic one No. 4.

The model 2 (as shown in Experiment 41) is inferior in speed to No. 1; but as regards all other qualities, so essential to every ship, particularly for burthen, very far the superior,—1st, in floating depth (see Experiment 43); 2nd, in not rolling; 3rd, in lateral resistance (see Experiment 44); 4th, in stability, the means of speed (see Table after Experiment 43).

The elliptic midship model (No. 4), as stated in the several experiments before adduced, is equal in speed to No. 2, but is slightly inferior to the same model,—1st, in depth of flotation; 2nd, by rolling more; 3rd, by having less lateral resistance; 4th, by possessing less stability.

The next point to be considered, before finally deciding upon the midship section, is, that part of a ship's midship which is above the load water-line—meaning the sides, whether they should be continued up perpendicularly, or slightly inclined outwards, so as to present at the lee-side a larger bearing on the water, to operate in an increasing ratio against the force of the wind upon the sails.

The Experiment 63 shows that the stability of the model (No. 1), having right-angled sides, equalled the stability of the model No. 2, with its sides inclining outward; and when both *were lightened*, the influence of the sides which inclined outwards became apparent in the stability remaining unaltered.

whereas in No. 1 the stability was improved to the amount of half an ounce : consequently there appears no good reason for giving a preference to the bevelling-out sides, over those carried up perpendicular.

From what has been elicited, it appears that any approach to the triangular midship section has its stability improved materially by ballast or weight ; for, in fact, it is indispensable, since it possesses none without ballast.

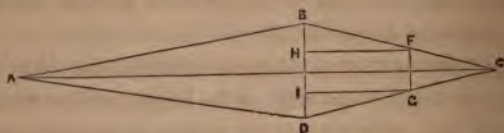
CHAPTER XVII.

The criticism of the four models of midship section being concluded, the inference to be drawn from it is, that (No. 2) the flat bottom exceeded all the others in the essential qualities for a ship of burthen. But since speed is now become so essential a quality in a ship, those curves must be adopted which have been proved so advantageous in Experiments 33, &c. Chapter VIII. ; and in consequence, the flat bottom can only be preserved entire at midships ; thus making the addition of a keel absolutely necessary, both before and after that point. No. 4, the elliptic form, comes next. When carrying out the experiments undertaken, with the object of ascertaining the effects of additional weight, for the purpose of gaining an increased depth of flotation in the six models, it appeared that a certain few of the models were influenced in their stabilities differently from the others.

The models in question were those which partook of, and approximated in their forms to, the parallelogram and square, and of the oval and circle ; and in these the stability increased *with the additional weight*. On the other hand, the long fish and bird-shape models ceased to improve in their stability after

a certain amount of weight, they having, as it were, an early limit to any further increase of the same. This peculiar characteristic (and confined almost to the two models Q and R) is of great moment when selecting forms for various purposes; and the cause of the same must be looked for in the narrowness or sharpness of such craft, particularly towards their head and stern.

The Experiment No. 8, and Table C, exhibits No. 2, with one-fifth of the base or beam for the depth of flotation, as possessing the greatest stability. Now, admitting the depth of flotation to be one-fifth at the midship, then the depth from the midship towards both head and stern must be greater than one-fifth,—indeed, be in an increasing ratio as the distance nears those extremities; consequently the stability diminishes proportionally, as shown in the same Table C, in No. 5, being inversely to the length; thus throwing the support of such parts upon the superior stability about the midship section; which, therefore, must necessarily be reduced. The annexed diagram will explain the meaning.



Let $ABCD$ be the model, and BD the midship section. Take any point in the sides BC and DC , as F , and draw the line FG parallel to BD ; likewise, draw FH , and GI , parallel to AC , cutting BD in H and I . Now, it is well known, that the straight line FG equals the straight line HI , which is part of the line BD . HI is less than BD ; so also must be its equal FG .

From hence it follows, that since BD is greater than FG , then is one-fifth of BD likewise greater than one-fifth of FG .

consequently the stability is proportionally less. The same can be shown of every line that may be drawn parallel to BD , between BD and the extremities A and C .

CHAPTER XVIII.

Presuming we are thus far correct, the difficulty then almost vanishes relative to models or forms of ships for particular services.

To begin with boats intended for speed, and to be impelled forward by the oar. Now it has been seen in Table No. 1, of the difference in speed between the six models when towed through the water, that the model I proved the swiftest. This model, in its proportion of length to breadth, is seven times the breadth. If greater speed be required, then eight, ten, or even twenty times the breadth may be selected, the midship section being semicircular, and to be situated at the middle of the length (see Experiment 75), or from that to an ellipse; but the utmost care will be requisite to prevent upsetting from its deficiency in stability.

For a steam vessel upon rivers, and without the aid of sails, ten times the beam or breadth, as the length, will be found to answer very well, with the midship section semicircular, and at the mid-length (see Experiment 75), or nearly so. Here iron and lead as ballast will greatly improve the stability; but then it will act as an extra load to carry.

When boats and steam vessels are to have the assistance of sails, the length should be about five times the breadth, as the model O .

For yachts, which are vessels for speed only, impelled forward by sail, and consequently requiring great stability, the model R , or between R and T , is the one most applicable

for the purpose. The floating depth, according to Table IV., must be very shallow, yet the keel with the bottom tapered should be made to descend down into the water sufficient to obtain the requisite lateral resistance, having the lower spaces filled with iron ballast, to further improve the stability for racing purposes; the masts, &c. being made proportionally strong.

Sea fishing-boats should closely resemble the model R also, because, although required for burthen rather than speed, great stability is absolutely necessary for the sake of safety, since such craft rarely have decks. Besides this, the cubic capacity of the form R is great, and at little cost, which is a consideration with fishermen. The sides also should be carried up high, both for safety and burthen.

The model Q presents the best form and requisites for the merchant service, which is made evident in Table No. III. The proportion of its length to breadth is three and a half the breadth. In the same Table (No. III.) it appears that when the oblong form of model, as P, is in length five times the beam, and possessing, as is there noted, greater stability than the model O, yet the model O beat P, and with less surface of sail, which is an advantage as requiring less weight of masts and yards.

Lastly, for ships of war, the model Q is here again pre-eminent for this purpose, particularly for the largest rates; because, in the first place, the stability increases in a degree with the load; and in the second place, of the greater bearing on the water at and towards both head and stern; and in the third, of the almost parallel sides, which afford every facility for the carrying of guns, with space to work them; but draught in the water should on no account be great, because speed is too essential a quality to be dispensed with in a man-of-war.

CHAPTER XIX.

THE POSITIONS OF THE CENTRE OF GRAVITY, OF THE
CENTRE OF LATERAL RESISTANCE, AND THE CENTRE
OF FORCE OF THE SAILS.

The position of the centre of gravity in a ship, with regard to its height above the keel, should not exceed, when loaded, the line of the surface of the water (see Experiment 8, Table C); otherwise it will lose stability and become top-heavy. If situated much lower than the water-line, the stability will certainly be improved; at the same time, a greater strain than needful will ensue upon the vessel, and thus endanger the breaking of the masts and yards, if they be not of sufficient dimensions to meet it. When the axis of the centre of gravity, considered lengthwise of a ship, exactly corresponds with the surface of the water, the rolling will be easy as far as the height of the said gravity is concerned; but the form of the midship section has very great influence in checking or increasing such motion. The distance from the head and stern in a ship at which the position of the centre of gravity had best be fixed requires no small degree of reflection, and must be decided before the laying down of the keel, because the circumstance involves both the places of the centre of lateral resistance and the centre of force of the sails.

The sole fish has the centre of gravity in the widest part of its breadth, and which, therefore, is its centre of motion. The distance of this point from each extremity of the fish is just two-fifths of its length from the head, and three-fifths from the tail; consequently, gives one-fifth as the excess of leverage at the tail over that at the head. In a fish this is most essential, *because it derives its power of locomotion chiefly from the rapid, lateral, and curved movements of the tail.*

A ship, which is a body impelled forward by sails, could by no means answer if constructed altogether upon the principle of the sole fish; and chiefly on account of the centre of gravity being so forward, as stated. The consequence in practice, from the great distance apart of the centres of gravity and lateral resistance, would be a perpetual conflict against each other for the centre of motion, to the positive disparagement of the speed; for, first, the influence of gravity would place the centre of motion at two-fifths of the length from the cutwater, second, the lateral resistance would operate to carry back the centre of motion towards the centre of length; and third, the centre of the force of the sails, if not situated well ahead by means of a long bowsprit, would be perpetually causing the ship's head to fly up into the wind. From all that has been stated, it appears in every way impolitic to have the centre of gravity situated too far forward.

In Experiments 73, &c. of the six models, it is shown that their centres of gravity taken in the solid state of the models themselves, previous to their being hollowed out—and, therefore, their true centres being likewise centres of displacement with regard to length,—are situated forward and a trifle more than their mid-length. Now, if the centre of lateral resistance be influenced by the head resistance, the two centres, namely, of gravity and lateral resistance, would nearly coincide. To accomplish this point, which insures the perfection, in a great measure, of easy sailing and steering vessels, it must be done through attention being given to lateral resistance at the time of making the design,—as by well slanting the cutwater, without however losing a good foot-hold, and deepening the keel towards and at the stern—whose post should be perpendicular, as length of keel operates with the best effect in improving lateral resistance,—whereas the deepening of a keel acts to overturn, and thus lessens the resistance (see Chapter XI.): by this means the two centres of gravity and lateral

resistance will be made to approximate very closely, or quite unite. Nothing now will remain to make perfect the sailing and steering but to place the centre of the effort of the sails perpendicularly over the two centres before named. If this be not effected, then whichever way the preponderance of the power of the sails operates, it will, if towards the stern, cause the head to fly up into the wind; and if towards the head, cause it to fly from the wind. The helm, which is the tell-tale, will counteract in part these propensities; likewise the reduction of sail at either stern or head, but that must be at the expense of speed.

If what has been stated be admitted to be correct, the three centres then ought to coincide as nearly as practicable, when the steerage will be easy, and only require the motion of the rudder to overturn the equilibrium to alter the course.

Again, the centre of gravity, though situated correctly as to its height, may yet be extremely injurious to easy motion of pitching and rising, if the heaviest weights be stowed very fore or aft. Instead of which, they ought to be placed at or near the position of the centre of gravity, the object being the rendering the vibration like a scale-beam, easy and without plunging. To fix the exact plan of stowage is out of the question; but it is best completed at sea, correcting any evils that may present themselves.

The place of the centre of gravity between the head and stern is ascertained pretty correctly by the surface of the water coinciding with the load water-line, obtained and laid down from a correct model. But the axis of its height is extremely difficult of detection; and the readiest mode which presents itself would be, the placing of three or more cups or open vessels filled with water, upon separate yet moveable shelves, a few inches or more perpendicularly above each other, at the centre of the ship's width and centre of gravity, taken

lengthwise. This being done, and a lateral rolling motion communicated to the ship artificially, or the taking advantage of a light wind upon smooth water, and observing particularly the surfaces of the water in the cups,—then if the water in any one of them be seen merely to rise up first on one side, afterwards on the other, but in the remaining cups if the motion of the water be more rapid, even to overflowing—that first cup, wherever situated, cannot be far from the axis of lateral motion. Should any doubt on this question arise, just shift the said cup a trifle higher or lower, until the due quietude of the water surface be obtained.

CHAPTER XX.

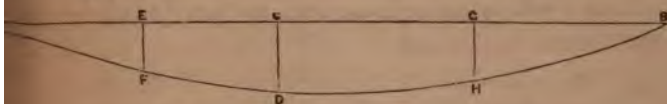
CONCLUSION.

Since curves must be substituted for the straight line in the forms of the bottoms of all vessels of speed, as proved, (see Experiments 33, &c. Chapter VIII.) and in consequence a keel is indispensable, the midship section, but particularly the parts fore and aft of the same, will partake more or less of the elliptic and angle shape.

From experiments made subsequent to those already given in Chapter XI., but not entered, and for the purpose of determining the perpendicular depth of the under-part of the keel at midships, from the load water-line of models with curved bottoms, it appeared that the depth to cause the greatest lateral resistance should not exceed the average breadth of half the beam measured at the points of equal distance between the midship and either end; unless the centre of gravity, by means of heavy ballast, as lead, be made to descend proportionally with any addition to the depth of the keel.

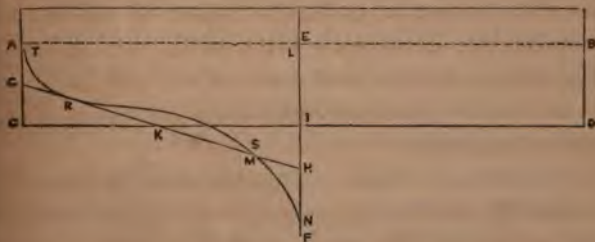
Again, as the above average depth is requisite for lateral resistance, then the midship form, and likewise the sections towards both head and stern, must be moulded into those shapes which will meet the object desired, with the least increase of displacement beyond the true one the vessel ought to possess when required for speed, as in Table IV. Chapter XV.

Let the above be exemplified in the models O, Q, and R, and the diagram here introduced will assist in the elucidation.



No. 1.—The model O. Scale, $\frac{1}{8}$ inch to 1 inch.

A C B D represents the half-part of the horizontal section of the model O, taken at the load water-line; c d being the midship, and e f, g h, the lines of the average beam.

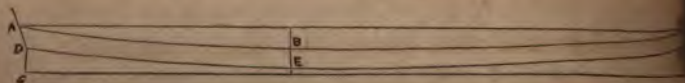


No. 2.—Midship section of model O. Scale, 1 inch to 1 inch.

Let A B D C be the midship section of the model O, when with the flat bottom; L I, the depth as stated in Table IV. Chapter XV. Now, in order to give speed to the model, the curved form must be applied to the bottom, which will cause the model to sink deeper into the water than before, by a one-

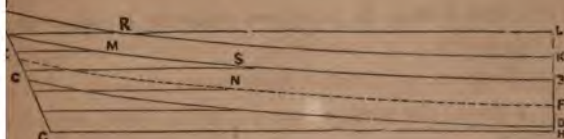
fourth part of LI , (see Chapter XVI.) or to the dotted line AEB .

Again, let EF equal the average breadth of beam, and F the bottom of the keel; but as every increase of the displacement beyond $ABDC$ will retard speed, yet the part of the dead wood and keel from I to F require support; it can only be carried into practice by transferring a portion of the capacity, or displacement at and about C , to between I and F . To this end, let K bisect the straight line CI , and G bisect AC ; from G draw through K the straight line GKH . By Euclid, the triangles GCK , KIH , are equal, therefore their displacements are equal. But since the keel from H to F will likewise need support, a curved brace may be applied from M to N , which will, however, cause some addition to the capacity; or the curve TMN may be substituted. To obviate the evil of additional capacity in some measure, the space may be filled with ballast, which, being situated low, will assist to compensate, by increasing the stability, and in consequence admit of an addition being made to the sail sufficient for the wind to impel forward the extra weight with nearly undiminished speed. The angle at G may be rounded off or not, but as it is, the original stability will be diminished by the removing of the triangle GCK to the triangle KIH , because it is sufficiently evident on inspection that the assumed centre of the triangle KIH , from the perpendicular line EF , is less than R , the centre of the triangle GCK ; therefore the power of buoyancy to aid stability is proportionally reduced, and which will not be altogether met by the ballast in the triangles KIH and MHN : the stability will again be lessened also if the angle at G is rounded off.



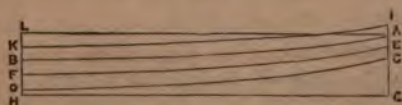
No. 3.—Bottom curves of model O. Scale, $\frac{1}{2}$ inch to 1 inch.

In the diagram No. 3, AC is the load water-line, AB , BC , bottom curves, and DE , EF , their union with the keel GH . Here is represented the part of the model situated between the head and the midship. AL the load water-line, AB the



No. 4.—Model O, from head to midship. Scale, $\frac{1}{4}$ inch to 1 inch.

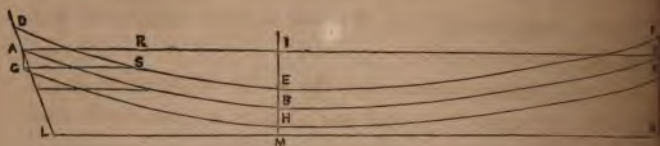
As in No. 3, B being the depth of E in No. 2, and the curve at the depth of A in No. 2, and CD the curve joining with the keel GH . The curves IK , AB , CD , and the dotted one EF , are all parallel to each other, and which must be carried out along the bottom of the ship in planes perpendicular to the horizon, and parallel to the ship's longitudinal axis. With regard to the lines EM , CN , &c., they must be drawn parallel to the load water-line to form a wedge of the bows, as repeated experiments, not entered, have determined the point over the bow curved alone; yet the outline of the hull curve should be preserved wherever the lines touch, and made to take the concave form, with the express view of promoting speed, by assisting the raising of the bows over the waves, particularly of sailing vessels against the downward pressure of the wind on their canvas.



No. 5.—Model O, from midship section to stern. Scale, $\frac{1}{8}$ inch to 1 inch.

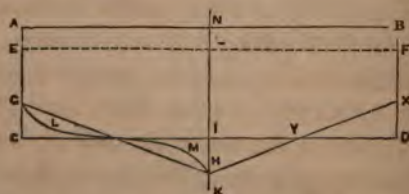
Let LA be the load water-line, BA , FE , DC , the curves, and

and the one uniting with the dead wood and keel. In this part of a ship no lines parallel with the load water-line are necessary, indeed they would be hindrances to speed, as has been shown already in the experiments. But in order to strengthen the dead wood and keel, short braces placed at the angle of 45° may be employed where thought requisite, but the less the better.



No. 6.—Midship section of model Q. Scale, $\frac{1}{8}$ inch to 1 inch.

AIC is the load water-line, AB, BC, DE, EF, are the bottom curves, and GH, HK, the union with the keel LN; AR, GS, are parallel horizontal lines, as in No. 4, to form the wedge bow. The stern part, meaning from midship to stern, need not (as before stated) the horizontal parallel line, but the curved form preserved throughout. The concave of the horizontal lines, as mentioned in treating of the bows of the model O, cannot be dispensed with.

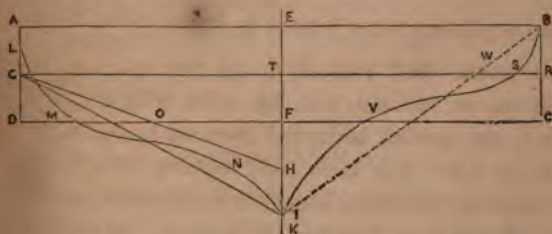


No. 7.—Model Q. Scale, $\frac{1}{2}$ inch to 1 inch.

Let ABCD be the midship section of the model Q, AB the load water-line, the depth being increased from EF to AB, as in diagram No. 2; NK the depth equal to the average breadth

of half the beam of the model Q, taken as in the model O. It is seen in this instance, that the depth from ι to κ is less than in No. 2; therefore the bottom may be preserved flat at the midship, with a straight or curved bracket, as it were, to support the keel, and continued fore and aft; or it may at once take the form as shown in the diagram by the letters HYX , XD being taken equal to IH , when the triangles HIY , XDY will be equal. Instead, however, of either of these, the outline may be as the curve $GLMH$.

AB the load water-line, ET the depth of flotation, as in Table IV. Chapter XV., with the addition of one-fourth part



No. 8.—Midship section of the model R. Scale, $\frac{1}{4}$ inch to 1 inch.

of the $\frac{1}{10}$ ths, in consequence of the curved bottom, making the total or one inch; which, according to the scale above, is half an inch, or BR ; therefore, $ABRG$ represents the true displacement. EK is the half-part of the average beam (see diagram R, in Experiment 82), in which the straight lines AB , DF , denote them; but they being drawn on the scale of $\frac{1}{2}$ inch to 1 inch, the average of the two, when doubled, will make it in the one-quarter inch scale, as the diagram above, equal to EK , K being the bottom of the keel.

It appears upon the right-hand part of the diagram, that in order to support the necessary depth of keel, as TK , it must either have the timber of the bottom framed at midship, as in the dotted straight line IB , or in the curved one $BSVK$. If

in the former, then the displacement will be doubled when completed on both sides of the model, and take proportionally the speed, as recorded in Table III. Chapter XV.; if the latter, still the original displacement will be increased, but equal in degree to the former. The keel, however, cannot be without support; therefore, of the two evils, the latter must be preferred whenever speed is to be gained.

The form on the left-hand side of the diagram, comprehended and denoted by the curve *L M N I*, is graceful and equal with regard to the keel; but then the displacement, on inspection, exceeds more than double (it must be admitted) the true displacement required, and therefore will take too much from the speed, as evidenced in Table III. Chapter XV., would answer well if the vessel be intended for burthen instead of a yacht.

Further Observations.

In the models having their horizontal section at the water-line, after the form of a bird, or fish, as the sole, it is seen that the midship section, or widest part, is situated two-fifths of their length from the head, and three-fifths from the stern. This is Nature's law, in order to counteract and balance the extra resistance the fore-body meets with against the air and water to what the aft-body is subject. In Chapter III. it is seen, when treating upon the law of lateral resistance, that when the model was drawn forward through the water as well as sideways, the centre of lateral resistance, at the time moved forward also; and the estimated proportion equal one-twelfth the length of the model.

Let this result be compared with Nature's form. Take the model 28 inches long, its middle will then be 14 inches from the head; divide 28 inches by 5, and the answer is $5\frac{1}{2}$ inches. Now $5\frac{1}{2}$ fifths of 28 = 11; and three-fifths = $16\frac{1}{2}$; and $14 - 11 = 3$.

or 3 inches, which is the distance before the centre of length where Nature places her greatest width in birds, and in the sole fish. With the model in Chapter III., one-twelfth was the supposed place before the centre of length, where the centre of lateral resistance resided when the body was moved both forward and sideways. The proportion of one-twelfth will be found to equal $2\frac{1}{2}$ inches, and rather more; being certainly less than 3 inches. It was stated, however, that increase of the speed of the model would cause the centre of lateral resistance to move still more forward. If granted, the average, allowing for mistakes, will be somewhere not far short of Nature's distance of 3 inches.

If the above statement be taken as near the truth, it follows, that whenever the line of greatest breadth of beam in a ship is situated aft the two-fifths of length, so as to destroy the balance of three-fifths of stern length, the evil must be compensated for by giving an equivalent in extra depth of keel towards and at the stern. Hence, the further aft the midship section be placed, the deeper must the keel be made, to preserve the due proportions of perpendicular surface of the two-fifths and three-fifths between the body before the midship and the body aft of the midship. Now, great depth of keel towards and at the stern is a serious evil in all ships destined for shallow waters; and is objectionable, in another point of view, as a respect of lee-way, on account of the greater power, from increased leverage, to overturn.

The forms of ships as regards beam to length, especially those for merchandise, should be regulated in a measure by the nature of the climate and sea in which they are destined to navigate. For if to encounter stormy winds and seas, whose average continuance is above that in other climates and seas, their breadth of beam and angle projections ought to be strongly kept in view, and acted upon by the

builders, to assist the stability. If, on the other hand, the winds and seas are comparatively moderate, less beam will be requisite, or greater length of vessel, and all angles dispensed with. Moreover, ships requiring much sail, in consequence of the breadth of beam, will need hands in proportion to manage the same; which circumstance, being an item of increased expenditure, will ever have its weight with the owners of merchantmen. This does not apply, however, to men-of-war, whose hands are generally in sufficient number for all duties.

With the completion of these few hints, which have been derived from careful experiments, observations, and reflections, although upon a small scale, I now take my leave, sincerely hoping they will induce persons of far more competent abilities than I possess, to engage in making investigations upon a large scale, that the true principles of ship-building may no longer continue a mystery.

W. B.

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1852.

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